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DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 178

STEEL RAILS FROM SINK-HEAD AND ORDINARY RAIL INGOTS

BY

GEORGE K. BURGESS, Physicist

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DECEMBER 15, 1920

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By George K. Burgess

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I. GENERAL PLAN OF INVESTIGATION

The results of the experimental rolling into rails of several types of ingots, including several designs of sink-head ingots and others, with the cooperation of the Maryland Steel Co., reported by Hadfield and Burgess,[1] looked sufficiently promising to the rail committee of the Pennsylvania Railroad to warrant the purchase of 100 tons of ingots cast by Sir Robert Hadfield in England, in order to make a more effective study of the suitability of this type of sink-head ingot for the manufacture of rails. It was also considered desirable to carry out similar series of tests of ingots of ordinary rail steel rolled at the same time and under as nearly identical conditions as possible in the same mill.[2] President F. W. Wood, of the Maryland Steel Co., Sparrows Point, Md., offered the facilities of that plant for this investigation, as in the case of previous experiments reported by Hadfield and Burgess. The rolling of ingots for the present investigation was done in 1915 at the Sparrows Point plant. The reduction of the results has been greatly delayed, but it is thought the subject matter is still of sufficient interest to warrant publication.

The planning of the details of the investigation, after correspondence with Sir Robert Hadfield, was made by A. W. Gibbs, chief mechanical engineer of Pennsylvania Railroad Co.; F. W. Wood, president of Maryland Steel Co.; and Dr. G. K. Burgess, chief, division of metallurgy, Bureau of Standards; and the tests were carried out by members of the technical staffs of their respective organizations, to whom acknowledgment is here made for their indispensable aid.

It was expected by Sir Robert Hadfield that the sink-head ingots made under this system would yield rails of remarkably high quality as regards "soundness, freedom from all piping and all segregation." From an inspection of the data concerning the manufacture of the ingots made by this process he also felt con-

[1] Hadfield and Burgess, Sound Steel Ingots and Rails, Trans. Am. Inst. Min. Engrs., **51**, pp. 862–880, 1915; J. Iron and Steel Inst., **91**, pp. 40–124, 1915.

[2] See also the valuable paper comparing American-made sink-head and ordinary ingots for rails by Edward F. Kenney: The Commercial Production of Sound and Homogeneous Steel, Am. Iron and Steel Inst., p. 144, 1915.

fident in stating: "This shows in a remarkable manner the uniformity of the ingots; also that every one of them is perfectly sound, free from blowholes, with no piping, and segregation below 8 per cent discard."

The results of the present investigation of 37 ingots of the Hadfield type show that he was not far astray in the confident prediction of uniformity, physical soundness, and freedom from chemical segregation. In fact, it is difficult to imagine 37 ingots, from as many heats of steel, more uniform in quality and properties and as free from those undesirable qualities and uncertainties that beset the ordinary ingot from which rails are made.

The ingots with which they were compared, the product of three heats, 5 from each heat, or 15 ingots in all, are not less instructive, in that each group, or heat, represents a distinct practice in open-hearth manufacture. In this investigation, therefore, from the point of view of steel making, we are really comparing the products rolled from 2 types of ingot representing 4 methods of manufacture.

The rolling, inspection, tests, and analyses were carried out with the greatest care, and by a series of actual weighings all the material from the several ingots was accounted for.

II. DETAILED SCHEME OF PROCEDURE

The detailed scheme of observations of rolling and tests of sink-head and comparison ingots follows:

1. INGOTS

Method of Numbering Ingots.—The sink-head ingots were numbered H1, H2, etc., ... H37, and the ingots made in the ordinary manner were numbered M1, M2, etc., ... M15.

Weight of Ingots.—The sink-head ingots were weighed cold and the others were weighed hot. The approximate weight of the sink-head ingots was 5300 pounds each and of the comparison ingots 7300 pounds.

Size and Shape of Ingots.—The English-made ingots were cast with sink head on large end, while the American-made ingots were cast small end up; dimensions of both types of ingot are shown in Table 1, and details concerning the sink heads of Hadfield ingots are to be found in Table 2.

Composition of Ingots.—Each sink-head ingot was from a separate heat, the compositions of which, furnished by the manufacturer, are given in Table 2. The American-cast ingots were from three heats, and their chemical compositions are shown in Table 3.

TEMPERATURE OF INGOTS.—The temperature of pouring of the comparison ingots is shown in Table 6; the temperature of the sink-head ingots was taken when they were introduced into the soaking pits, the temperatures of which were also noted then and at intervals until the ingots were withdrawn from the soaking pits; the temperature of English (Table 7) and comparison (Table 8) ingots were also taken at the blooming mill. In Table 9 are shown typical ingot-rolling temperatures of both types of ingot.

INSPECTION OF INGOTS.—The sink-head ingots were inspected cold for surface defects, cracks, etc., and at the blooming mill during rolling for the existence and location of cracks, scrap, etc. (Table 4). The other ingots were similarly inspected at the blooming mill (Table 5).

DISPOSITION OF INGOTS.—Of the 37 sink-head ingots cast at Sheffield, 35 were rolled into blooms at the Sparrows Point mill, and the remaining 2 ingots were sectioned longitudinally for metallographic examination. The examination of H32 was made by the Bureau of Standards and that of H37 by Hadfields (Ltd.). In addition to splitting 2 ingots, it was also decided to examine similarly top blooms from one of each of the two types of ingot, H5 and M10. The blooms and ingots examined in this manner were selected at random. All blooms were rolled into rails directly without reheating, and all material was accounted for by actual weighing, as shown in Tables 10 and 11.

TABLE 1.—Dimensions of Ingots of Both Types

Part measured	Sink-head ingot	Comparison ingot
	Inches	Inches
Top	19½ by 19½	18¼ by 18¼
Bottom	17¼ by 17¼	19¼ by 19¼
Height	[a] 50½	63

[a] The height given is exclusive of the height of sink head, which was approximately 13¾ inches.

TABLE 2.—Results of Chemical Analyses and Head Particulars of Sink-Head Ingots [a]

Ingot number	Heat number	Chemical composition (percentages)					Sink-head particulars			
		C	Si	S	P	Mn	Height to which filled in head	Depth of settling	Capacity of cavity	Percentage of settling to total bulk of ingot
							Inches	Inches	Cm^3	
H1	4774	0.65	.....	0.040	.....	0.94	14.00	8.25	9950	3.19
H2	4738	0.63–.64	.....	.042	.....	.91	13.50	9.00	10300	3.31
H3	4847	.63–.64	.....	.047	.....	.93	13.75	9.25	10450	3.37
H4	4915	.65–.66	.....	.049	.....	.92	14.00	9.75	9675	3.10
H5	4873	.69	.....	.050	.....	.95	14.00	9.38	10250	3.29
H6	4939	.63–.64	0.16	.045	0.028	.92	13.00	7.50	8800	2.84
H7	4627	.64	.....	.052	.....	.97	14.00	8.25	9600	3.08
H8	4680	.65	.14	.049	.029	.92	13.75	8.50	10250	3.29
H9	4709	.58	.....	.049	.....	.93	13.00	7.75	8930	2.88
H10	5085	.63–.64	.16	.042	.031	.86	13.25	9.25	11000	3.52
H11	5018	.64	.16	.039	.031	.92	14.00	8.75	10040	3.21
H12	4641	.67–.69	.....	.045	.....	.92–.94	14.50	8.50	9000	2.89
H13	5059	.63–.64	.....	.049	.....	.92	14.00	8.88	10750	3.44
H14	4835	.69	.....	.046	.....	.91	13.50	7.75	9520	3.05
H15	4978	.67–.68	.....	.051	.....	.96	14.50	9.88	9260	2.95
H16	4992	.66	.....	.045	.....	.94	13.50	9.75	9000	2.88
H17	4825	.66	.....	.045	.....	.92	13.50	6.88	9000	2.89
H18	4829	.66	.....	.041	.....	.98	14.00	8.50	11100	3.55
H19	5073	.63–.64	.....	.045	.....	.90	14.00	9.50	10500	3.37
H20	4696	.66	.....	.038	.....	.96	13.50	6.50	8600	2.77
H21	4801	.66	.....	.036	.....	.95	13.50	8.13	9150	2.90
H22	4723	.63	.....	.044	.....	.95	13.50	8.00	9900	3.17
H23	5046	.62–.63	.....	.042	.....	.93	13.50	7.00	10500	3.37
H24	5030	.60	.....	.056	.....	.94	13.50	10.13	11950	3.82
H25	4668	.58	.....	.042	.....	.93	14.50	8.50	10100	3.24
H26	4813	.64	.14	.048	.032	.93	14.00	8.63	10800	3.45
H27	4615	.64	.20	.048	.....	1.01	14.25	7.00	9000	2.89
H28	4588	.64	.19	.047	.....	.97	13.00	7.25	8930	2.86
H29	4908	.64	.....	.041	.....	.84	14.00	8.75	9750	3.11
H30	4861	.61–.62	.21	.045	.031	.92	14.00	9.63	10900	3.49
H31	4600	.65	.15	.049	.....	.96	13.50	8.50	9825	3.16
H32	5004	.65	.....	.052	.....	.94	14.00	8.50	10175	3.27
H33	4761	.65	.....	.048	.....	.90	13.50	8.50	10800	3.47
H34	5099	.63–.64	.....	.039	.....	.86	11.00	8.88	10040	3.34
H35	4887	.63	.....	.050	.....	.89	14.00	9.00	10500	3.36
H36	4653	.61	.....	.053	.....	.85	13.50	7.75	9900	3.17

[a] Furnished by Sir Robert Hadfield.

TABLE 3.—Results of Chemical Analyses of Maryland Steel

Heat number	Ingot numbers	Elements determined (percentages)						
		C	Si	S	P	Mn	Cr	Ni
2 x 4497	M1 –M5, inc.	.608–0.630	0.148	0.067	0.010	0.710–0.720	0.270	0.760
1 x 3632	M6 –M10, inc.	.642– .654	.185	.092	.014	.650– .660	.290	.780
2 x 4510	M11–M15, inc.	.642– .650	.191	.097	.019	.760– .810	.270	.760

TABLE 4.—Results of Inspection of Sink-Head Ingots and Blooms

Ingot number	Results of inspection of cold ingots for cracks, scrap, etc.	Time of charging ingots into pits	Time of drawing ingots from pits	Interval in pits	Time consumed in rolling in blooming mill	Results of inspection during rolling in blooming mill
					Min. sec.	
24	1 side—bad splash in pouring, 1 rough corner	4:35 p. m. to 4:40 p. m., Aug. 15, 1915.	11:56 a. m. to 12:25 p. m., Aug. 16, 1915.	19 hrs., 32 mins.	2 10	Very small piece of scrap on one corner.
28	1 side—bad splash in pouring bottom half, 1 rough corner				2 22	Very small piece of scrap on sides and corners.
2	1 side rough, 2 rough corners				2 25	1 crack 18 inches from top on side of ingot.
15	1 side very rough near top, 2 rough corners				2 15	2 small cracks on corners 2 feet from top of ingot.
1	Sides good, 2 rough corners				2 10	Spot of scrap 2 feet from top.
21	1 rough side, 1 rough corner				2 20	Spot of scrap 2 feet from top. Small crack on corner 2 feet from top.
9	3 rough sides, 1 rough corner	4:45 p. m. to 4:52 p. m., Aug. 15, 1915.	12:29 p. m. to 12:46 p. m., Aug. 16, 1915.	19 hrs., 49 mins.	2 25	Cracked all around ingot at bottom of sink-head.
7	Sides O. K., 2 rough corners				2 15	Small spot of scrap 8 inches from top on corners.
35	3 sides—rough spots 1 foot from bottom, 1 rough corner				2 35	Small spots of scrap all over ingot.
13	3 rough sides, 2 rough corners				2 20	Small spots of scrap 12 inches from bottom.
22	1 side—bad splash in pouring, 1 rough corner				2 10	Small spots of scrap on corners 2 feet from bottom.
14	2 sides—splashed in pouring, 3 rough corners				2 20	Clean bloom.
19	1 side—bad splash in pouring, 2 rough corners	4:30 p. m. to 4:38 p. m., Aug. 16, 1915.	1:49 p. m. to 2:05 p. m., Aug. 17, 1915.	21 hrs., 22 mins.	1 30	Small spot of scrap on corner 1 foot from top.
26	1 side rough 1 inch from top, 2 rough corners				2 15	Small spots of scrap 2 feet from top.
18	1 side—bad splash in pouring, corners good				2 15	Cracked at bottom of sink-head.
6	2 sides—bad splash in pouring, 2 rough corners				2 20	1 small spot of scrap 4 feet from top and one 1 foot from bottom on sides.
23	2 sides—bad splash in pouring, 1 rough corner				2 25	
31	1 side—bad splash in pouring near bottom, 2 rough corners				2 30	1 spot of scrap 1 foot from top on side. Clean bloom. Clean bloom.
29	1 side—crack in mold 10 inches from top, 2 rough corners. 2 sides—rough spots in center	4:50 p. m. to 5:05 p. m., Aug. 16, 1915.	2:06 p. m. to 2:22 p. m., Aug. 17, 1915.	21 hrs., 15 mins.	2 40	Spots of scrap on corners and sides 18 feet from top.
36	2 sides—rough spots 1 foot from bottom, corners good				.. ..	
4	4 sides—splash in pouring, 2 rough corners				2 20	Small spot of scrap 2 feet from top.
11	2 sides—splash in pouring, 2 rough corners				2 15	Spots of scrap at center across the corners.
12	1 side—splash in pouring, corners good				2 20	Small spots of scrap all over the top third of ingot.
10	Sides good, 3 rough corners				2 25	Small spots of scrap 2 feet from top on corners and sides.
					2 30	Small spots of scrap 3 feet from bottom on corners.
16	2 sides—rough 2 feet from bottom, 1 rough corner	4:30 p. m. to 4:45 p. m., Aug. 17, 1915.	9:51 a. m. to 10:10 a. m., Aug. 18, 1915.	17 hrs., 22 mins.	2 20	Small spot of scrap 1 foot from top on corner.
20	2 sides rough, 3 rough corners				2 15	Clean bloom. Cracked at bottom of sink-head.
33	3 sides—bad splash in pouring 1 foot from top, 1 rough corner				2 20	Small spot of scrap at center on sides.
17	1 side—splash in pouring, 2 rough corners				2 20	Large spots of scrap on all sides.
30	3 sides—splash in pouring at center, 2 rough corners				2 15	Small spots of scrap 2 feet from top on sides.
27	1 side—splash in pouring 2 feet from bottom, 1 rough corner				2 30	Small spots of scrap on all sides. Cracked at bottom of sink-head.
8	1 side—splash in pouring 6 inches from bottom, 1 rough corner.	4:45 p. m. to 5:00 p. m., Aug. 17, 1915.	10:14 a. m. to 10:27 a. m., Aug. 18, 1915.	17 hrs., 28 mins.	2 25	Large spot of scrap at center of ingot on one side.
3	2 rough sides, 2 rough corners				2 40	Small spot of scrap 2 feet from top.
25	3 sides—splash in pouring, 1 rough corner				2 20	Large spot of scrap 2 feet from top on corner.
34	1 side rough at center, 2 rough corners				2 50	Large spots of scrap on all sides.
5	1 side—splash in pouring, corners good				2 25	Small spots of scrap on sides.
32	1 side—splash in pouring, 2 rough corners				.. ..	Not rolled.

TABLE 5.—Time Consumed in Rolling and Results of Inspection of Comparison Ingots and Blooms

Ingot number	Date rolled	Heat number	Time in molds	Time in soaking pits	Time consumed in rolling in blooming mill	Results of inspection during rolling in blooming mill
			Min.	H. M.	M. S.	
1	Aug. 16, 1915	2x4497	20	2 10	2 25	1 corner and 1 side cracked 1 foot from bottom.
2	do	2x4497	20	2 14	1 50	Small spot of scrap 2 feet from top on corner.
3	do	2x4497	20	2 18	2 35	Clear bloom.
4	do	2x4497	20	2 21	2 ..	Do.
5	do	2x4497	20	2 23	2 ..	Do.
6	Aug. 18, 1915	1x3632	23	1 40	1 50	Two small side cracks 4 feet from bottom.
7	do	1x3632	23	1 40	1 45	Clear bloom.
8	do	1x3632	23	1 41	2 10	Do.
9	do	1x3632	23	1 43	1 55	Do.
10	do	1x3632	23	1 45	2 10	1 small side crack 5 feet from bottom.
11	do	2x4510	30	2 15	2 ..	Clear bloom.
12	do	2x4510	30	2 15	2 ..	Small side crack 3 feet from top.
13	do	2x4510	30	2 17	2 ..	Clear bloom.
14	do	2x4510	30	2 19	2 10	Small side crack 3 feet from top.
15	do	2x4510	30	2 20	2 5	Small side crack 2 feet from bottom.

TABLE 6.—Pouring Temperatures of Comparison Ingots [a]

Observation number	Temperature for heat 1x3632	Temperature for heat 2x4510	Observation number	Temperature for heat 1x3632	Temperature for heat 2x4510
	°C	°C		°C	°C
1	.....	1557	16	1543	1522
2	.....	1545	17	1533	1512
3	[b] 1596	[c] 1545	18	1533	1507
4	[b] 1587	[c] 1538	19	1539	1497
5	[b] 1564	[c] 1540	20	1523	.....
6	[b]	[c] 1528	21	1539	.....
7	[b] 1578	[c] 1531	22	1537	.....
8	1559	1532	23	1537	.....
9	1557	1537	24	1529	.....
10	1557	.....			
11	1549	1527			
12	1557	1531			
13	1547	1521			
14	1551	1533			
15	1539	1527			

[a] Pouring temperatures group M1–M5, inclusive, not taken.
[b] Ingots from group M6–M10, inclusive. (Average pouring temperature, 1581°C.)
[c] Ingots from M11–M15, inclusive. (Average pouring temperature, 1536°C.)

TABLE 7.—Temperatures of Working of Sink-Head Ingots

Ingot number	Temperature of soaking pits		Ingot temperature		Rail temperature at finishing pass (taken on base of rail)	
	At time of charging ingots	After 14½ hours	When drawn	Blooming mill	First rail bar	Second rail bar
	°C	°C	°C	°C	°C	°C
1	700	1310	1300	1130	1016	1007
2	700	1310	1300	1140	1030	1020
15	700	1310	1300	1137	1026	1017
21	700	1310	1300	1123	1025	1005
24	700	1310	1300	1172	1025	1010
28	700	1310	1300	1157	1019	1008
7	750	1300	1290	1125	1028	998
9	750	1300	1290	1149	1024	1016
13	750	1300	1290	1116	1034	1008
14	750	1300	1290	1143	1043	1019
22	750	1300	1290	1144	1032	1018
35	750	1300	1290	1140	1034	1011
6	650	1200	1295	1149	1048	1025
18	650	1200	1295	1166	1032	1023
19	650	1200	1295	1180	1069	1044
23	650	1200	1295	1154	1047	1026
26	650	1200	1295	1173	1047	1034
31	650	1200	1295	1146	1036	1016
4	650	1240	1280	1156	1040	1016
10	650	1240	1280	1147	1046	1022
11	650	1240	1280	1136	1029	1012
12	650	1240	1280	1142	1047	1029
29	650	1240	1280	1148	1034	1005
36	650	1240	1280	1136	1038	1016
16	600	1305	1515	1182	1018	955
17	600	1305	1515	1164	1036	1016
20	600	1305	1515	1179	1045	1023
27	600	1305	1515	1153	1040	1024
30	600	1305	1515	1157	1032	1020
33	600	1305	1515	1160	1029	1017
3	600	1300	1316	1156	1033	1023
5	600	1300	1316	1149	.....	.....
8	600	1300	1316	1151	1029	1023
25	600	1300	1316	1153	1035	1000
34	600	1300	1316	1140	1014	1004
Average	658	1276	1299	1150	1034	1014
Maximum	750	1310	1315	1182	1069	1044
Minimum	600	1200	1280	1116	1014	955

TABLE 8.—Temperatures of Working of Comparison Ingots

Ingot number	Ingot temperature in blooming mill	Rail temperature at finishing pass (taken on base of rail)	
		First rail bar	Second rail bar
	°C	°C	°C
1	1149	1026	1006
2	1173	1016	993
3	1164	1040	1025
4	1179	1053	1039
5	1177	1064	1027
6	.....	1031	1005
7	1167	1029	1018
8	1176	1030	1001
9	1159	1038	1009
10	1180	1038	.....
11	1162	1039	1003
12	1181	1046	1025
13	1161	1032	1018
14	1149	1025	1016
15	1149	1024	1018
Average	1166	1035	1001
Maximum	1181	1064	1039
Minimum	1149	1016	993

TABLE 9.—Typical Rolling Temperatures

Temperature of sink-head ingot number							Temperature of comparison ingot number					
7	13	14	19	28	30	34	2	5	7	10	13	15
°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C
1136	1157	1152	1212	1181	1195	1165	1184	1173	1179	1206	1179	1168
1147	1114	1147	1212	1171	1179	1165	1171	1184	1179	1198	1171	1157
1144	1103	1136	1176	1152	1165	1157	1168	1176	1176	1177	1168	1136
1114	1109	1147	1176	1147	1147	1141	1184	1176	1160	1179	1157	1149
1123	1109	1141	1160	1147	1147	1131	1171	1179	1163	1173	1157	1147
1125	1128	1141	1165	1147	1139	1123	1165	1184	1157	1168	1147	1136
1112	1093	1139	1165	1147	1144	1120	1163	1179	1157	1163	1147	1144
1103	.....	.....	.....	.....	1141	1125	.....	1147	.....	.....	.....	.....
Average							Average					
1125	1116	1143	1180	1157	1157	1141	1173	1177	1167	1180	1161	1149

	°C		°C
Grand average	1145	Grand average	1168
Maximum	1212	Maximum	1206
Minimum	1093	Minimum	1136

TABLE 10.—Disposition of Material from Sink-Head Ingots

[Weight in pounds. Discard made only to physically sound steel. H_5 not included in this table as the top bloom for this ingot was sent to the Bureau of Standards]

Ingot number	Ingot weight	Bloom crops				Weight of the four test pieces each 6 inches long	Rail crops at hot saw		
		Top		Bottom			Middle		Bottom
		Weight	Per cent of ingot, average	Weight	Per cent of ingot, average		No. 1	No. 2	
ROLLED AUG. 16, 1915									
24	5300	185	3.5	297	5.6	86	77	60	259
28	5300	233	4.4	112	2.1	79	74	32	30
2	5300	155	2.9	113	2.1	79	66	30	21
15	5300	167	3.2	129	2.4	79	83	31	48
1	5300	190	3.4	123	2.3	77	59	38	30
21	5300	442	8.4	116	2.2	85	43	77	75
9	5300	294	5.5	131	2.5	79	46	75	89
7	5250	234	4.5	122	2.3	79	54	54	74
35	5300	280	5.3	161	3.0	77	46	48	50
13	5300	191	3.6	141	2.7	81	58	39	58
22	5250	437	8.3	123	2.3	81	47	45	54
14	5300	231	4.4	138	2.6	78	53	50	67
ROLLED AUG. 17, 1915									
19	5300	160	3.0	120	2.3	77	49	50	69
26	5300	160	3.0	130	2.5	75	47	53	70
18	5300	237	4.5	116	2.2	76	50	77	99
6	5300	324	6.1	127	2.4	77	44	56	69
23	5350	134	2.5	131	2.4	78	49	79	100
31	5300	234	4.4	109	2.1	74	54	28	49
29	5350	566	10.6	123	2.3	77	44	63	78
36	5300	342	6.5	142	2.7	76	50	47	71
4	5350	270	5.0	123	2.3	71	50	46	56
11	5300	325	6.1	136	2.7	73	73	39	61
12	5350	204	3.8	124	2.3	74	54	60	97
10	5250	320	6.1	130	2.5	78	46	57	61
ROLLED AUG. 18, 1915									
16	5350	199	3.7	154	2.9	74	37	56	79
20	5300	276	5.2	122	2.3	73	43	66	72
33	5300	228	4.3	148	2.8	75	49	78	93
17	5300	145	2.7	117	2.2	74	53	73	93
30	5300	247	4.7	112	2.1	74	45	79	117
27	5300	245	4.7	97	1.9	78	57	63	71
8	5300	142	2.7	119	2.3	78	53	75	86
3	5300	205	3.8	115	2.2	71	81	55	65
25	5300	160	3.0	151	2.8	77	64	57	72
34	5300	195	3.7	166	3.2	83	58	43	57
Total	179 700	8357	4.3	4519	2.5	2623	1856	1879	2540

TABLE 10—Disposition of Material from Sink-Head Ingots—Continued

ROLLED AUG. 16, 1915—Continued

Ingot number	Ingot weight	Weight of rails				Total weight rolled, including crops and test pieces	Loss	
		A	B	C	D		Weight	Per cent of ingot, average
24	5300	768	1111	1117	1122	5082	218	4.1
28	5300	1232	1112	1120	1121	5145	155	2.9
2	5300	1315	1119	1120	1123	5141	159	3.0
15	5300	1277	1115	1120	1123	5172	128	2.4
1	5300	1284	1116	1122	1123	5162	138	2.6
21	5300	941	1121	1121	1124	5145	155	2.9
9	5300	1096	1121	1117	1119	5167	133	2.5
7	5250	1203	1116	1119	1122	5177	73	1.4
35	5300	1172	1113	1115	1118	5180	120	2.3
13	5300	1289	1116	1118	1120	5211	89	1.7
22	5250	1032	1116	1117	1122	5174	76	1.4
14	5300	1228	1113	1115	1117	5190	110	2.1

ROLLED AUG. 17, 1915—Continued

19	5300	1175	1108	1112	1115	5035	265	5.0
26	5300	1226	1108	1110	1112	5091	209	3.9
18	5300	1130	1107	1111	1115	5118	182	3.4
6	5300	1035	1107	1111	1111	5061	239	4.5
23	5350	1183	1102	1105	1109	5070	280	5.2
31	5300	1191	1100	1110	1117	5066	234	4.4
29	5350	867	1107	1111	1111	5147	203	3.8
36	5300	1082	1106	1106	1113	5135	165	3.1
4	5350	1228	1106	1107	1111	5168	182	3.4
11	5300	1161	1107	1116	1114	5205	95	1.8
12	5350	1194	1101	1107	1114	5129	221	4.1
10	5250	1077	1110	1114	1115	5108	142	2.7

ROLLED AUG. 18, 1915—Continued

16	5350	1191	1111	1111	1115	5127	223	4.2
20	5300	1175	1107	1111	1113	5158	142	2.7
33	5300	1153	1107	1112	1112	5155	145	2.7
17	5300	1269	1107	1113	1115	5159	141	2.7
30	5300	1151	1111	1112	1113	5161	139	2.6
27	5300	1229	1119	1120	1121	5200	100	1.9
8	5300	1274	1117	1109	1112	5165	135	2.5
3	5300	1204	1103	1106	1109	5114	186	3.5
25	5300	1275	1104	1109	1112	5181	119	2.2
34	5300	1157	1105	1115	1113	5092	208	3.9
Total	179 700	39 464	37 749	37 859	37 946	174 791	5519	3.0

TABLE 10.—Disposition of Material from Sink-Head Ingots—Continued

ROLLED AUG. 16, 1915—Continued

Ingot number	Ingot weight	Discard in rail on account of—			Material discarded to physically sound steel		Material available for rails			Ingot rolled with no draft on
		Sink head	Pipe	Total	Weight	Per cent of original ingot, average	Weight	Per cent of original ingot, average	Net per cent of ingot, average	Pass number
24	5300	161	.....	161	346	6.5	4043	76.3	87.8	1
28	5300	163	.....	163	396	7.5	4501	84.9	89.2	1
2	5300	230	.....	230	385	7.3	4526	85.4	88.9	1
15	5300	310	.....	310	477	9.0	4404	83.1	88.1	2
1	5300	292	.....	292	482	9.1	4430	83.5	87.8	2
21	5300	162	.....	162	604	11.1	4230	79.8	84.8	2
9	5300	.....	.....	.....	294	5.5	4532	85.5	91.8	1
7	5250	235	.....	235	469	8.9	4404	83.9	88.2	1
35	5300	160	.....	160	440	8.3	4435	83.7	88.6	1
13	5300	80	.....	80	271	5.1	4644	87.6	92.7	2
22	5250	.....	.....	.....	437	8.3	4468	85.1	88.8	2
14	5300	284	.....	284	515	9.7	4367	82.4	97.5	2

ROLLED AUG. 17, 1915—Continued

19	5300	326	.....	326	486	9.2	4261	80.4	85.0	1
26	5300	233	.....	233	393	7.4	4398	83.0	87.9	1
18	5300	.....	324	324	561	10.5	4215	79.5	85.0	1
6	5300	158	.....	158	482	9.1	4283	80.8	85.5	2
23	5350	291	.....	291	425	7.9	4286	80.1	86.7	2
31	5300	237	.....	237	471	8.9	4355	82.2	86.0	2
29	5350	64	.....	64	630	11.8	4209	78.7	84.3	1
36	5300	73	.....	73	415	7.8	4410	83.2	88.4	1
4	5350	87	162	249	519	9.7	4374	81.8	87.0	1
11	5300	254	.....	254	579	10.9	4317	81.5	86.4	2
12	5350	367	.....	367	571	10.7	4223	78.9	85.1	2
10	5250	148	.....	148	468	8.9	4346	82.8	86.8	2

ROLLED AUG. 18, 1915—Continued

16	5350	305	.....	305	504	9.4	4297	80.4	86.4	1
20	5300	313	.....	313	589	11.1	4266	80.5	85.4	1
33	5300	281	.....	281	509	9.6	4278	80.7	86.7	1
17	5300	342	.....	342	487	9.1	4336	81.8	87.4	2
30	5300	270	.....	270	517	9.8	4291	80.9	86.8	2
27	5300	233	.....	233	478	9.0	4434	83.7	88.5	2
8	5300	346	.....	346	488	9.1	4344	82.0	87.5	1
3	5300	378	.....	378	583	11.0	4215	79.5	84.6	1
25	5300	340	.....	340	500	9.4	4337	81.8	87.5	1
34	5300	389	.....	389	584	11.0	4184	78.9	84.1	2
Total	179 700	7512	486	7998	16 355	9.1	147 643	81.9	87.9	.....

TABLE 11.—Disposition of Material from Comparison Ingots

[Weights in pounds. Discard made only to physically sound steel]

HEAT NO. 2x4497

Ingot number	Ingot weight	Bloom crops				Weight of the five test pieces, each 6 inches long
		Top		Bottom		
		Weight	Per cent of ingot, average	Weight	Per cent of ingot, average	
1	7360	183	2.4	276	3.7	90
2	7030	243	3.4	209	2.9	98
3	7040	185	2.6	143	2.0	100
4	7130	189	2.6	226	3.1	95
5	7190	223	3.1	175	2.4	101
	35 750					

HEAT NO. 1x3632

6	7340	189	2.5	291	3.9	93
7	7200	205	2.8	215	2.9	90
8	7260	188	2.5	215	2.9	90
9	7240	225	3.1	252	3.4	93
	29 040					

HEAT NO. 2x4510

11	7510	664	8.8	236	3.1	96
12	7340	288	3.9	254	3.4	89
13	7190	490	6.8	175	2.4	88
14	7320	379	5.1	210	2.8	95
15	7480	236	3.1	235	3.1	96
	36 840					
Total	101 630	3887	3.8	3112	3.0	1314

HEAT NO. 1x3632

10		3315		230		97

HEAT NO. 2x4497—Continued

Ingot number	Ingot weight	Rail crops at hot saw			Weight of rails					
		Middle		Bottom	X	A	B	C	D	E
		No. 1	No. 2							
1	7360	48	58	71	930	1117	1117	1117	1123	1126
2	7030	84	96	94	517	1114	1115	1117	1120	1122
3	7040	95	92	74	675	1110	1109	1115	1117	1119
4	7130	147	81	37	660	1108	1108	1115	1116	1120
5	7190	89	100	59	774	1108	1109	1113	1115	1119
	35 750									

HEAT NO. 1x3632—Continued

6	7340	44	63	75	878	1118	1118	1121	1121	1123
7	7200	34	56	28	880	1116	1114	1117	1122	1122
8	7260	60	59	73	888	1111	1112	1122	1120	1120
9	7240	23	59	94	783	1118	1118	1122	1123	1125
	29 040									

HEAT NO. 2x4510—Continued

11	7510	36	87	145	591	1102	1106	1111	1110	1116
12	7340	48	76	115	826	1105	1103	1106	1108	1111
13	7190	42	29	123	625	1101	1101	1104	1104	1106
14	7320	37	80	127	775	1099	1099	1104	1101	1103
15	7480	69	70	123	1011	1103	1106	1107	1109	1108
	36 840									
Total	101 630	856	1006	1238	10 813	15 530	15 535	15 591	15 609	15 640

HEAT NO. 1x3632—Continued

10			68	140				1115	1116	1117

TABLE 11.—Disposition of Material from Comparison Ingots—Continued

HEAT NO. 2x4497—Continued

Ingot number	Ingot weight	Total weight rolled, including crops and test pieces	Discard in rail on account of pipe	Material discarded to physically sound steel		Material available for rails			Date rolled
				Weight	Per cent of original ingot, average	Weight	Per cent of original ingot, average	Per cent of net ingot, average	
1	7360	7256	505	688	9.3	6115	83.1	88.5	Aug. 16, 1915
2	7030	6929	.....	243	3.4	6203	88.2	94.8	Do.
3	7040	6934	.....	185	2.6	6345	90.1	95.8	Do.
4	7130	7002	336	525	7.4	5986	83.9	90.2	Do.
5	7190	7085	.....	223	3.1	6439	89.5	95.0	Do.
	35 750	.....	.....	1864	5.2	31 088	86.9	92.8	

HEAT NO. 1x3632—Continued

6	7340	7234	505	694	8.2	6067	82.6	88.3	Aug. 18, 1915
7	7200	7099	505	710	9.8	6056	84.1	88.2	Do.
8	7260	7158	163	351	4.8	6400	88.1	93.5	Do.
9	7240	7135	336	561	7.7	6146	84.8	90.4	Do.
	29 040	.....	.....	2316	8.0	24 669	85.0	90.2	

HEAT NO. 2x4510—Continued

11	7510	7400	1515	2179	29.0	4717	62.8	67.4	Aug. 19, 1915
12	7340	7229	336	624	8.5	6112	83.2	89.2	Do.
13	7190	7088	2356	2846	39.5	3873	53.8	56.7	Do.
14	7320	7209	1682	2061	28.2	4694	64.1	68.3	Do.
15	7480	7373	1815	2051	27.4	4825	64.5	69.1	Do.
	36 840	.....	.....	9761	26.5	24 221	65.8	70.2	
Total	101 630	100 131	10 054	13 941	13.7	79 978	78.7	83.8	

HEAT NO. 1x3632—Continued

10	.....	7180	.....	.....	.....	.....	.....	.....	Aug. 18, 1915

Blooming Mill.—All ingots were rolled in 13 passes in a two-high mill to blooms 8 by 8⅛ inches. The English made ingots entered the blooming mill with the sink head toward the rolls. One half received the first, or "squaring up," pass in this direction, no draft being given on second pass; the other half were given no draft on the first pass, the "squaring up" being done on pass No. 2 (Table 10). The comparison ingots were rolled according to ordinary practice, entering the rolls the small end first.

2. BLOOMS

Each ingot was cut into 2 blooms (8 by 8⅛ inches) as shown in Figs. 1 and 2, and rolled directly into rails, that is, without reheating of blooms. The second bloom from sink-head ingots made 2 rails (C and D), and that from the comparison ingots made

3 rails (C, D, and E). The first bloom from the sink-head type of ingot made a B and, generally, a short A rail; the first bloom from the comparison type of ingot made a B, A, and (short) X rail. The blooms were sheared top and bottom as little as possible for the safe passage of the bar through the rolls. Each piece cut was marked, weighed, and preserved.

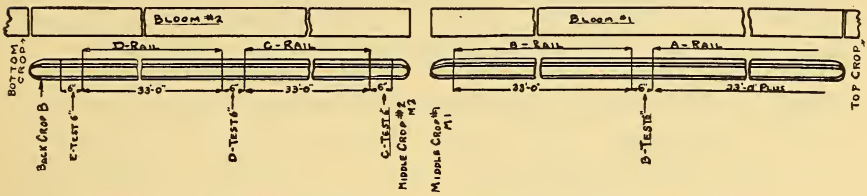


FIG. 1.—*Method of cutting blooms and rails from sink-head ingots*

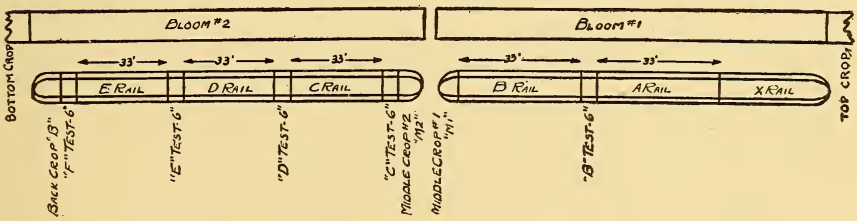


FIG. 2.—*Method of cutting blooms and rails from comparison ingots*

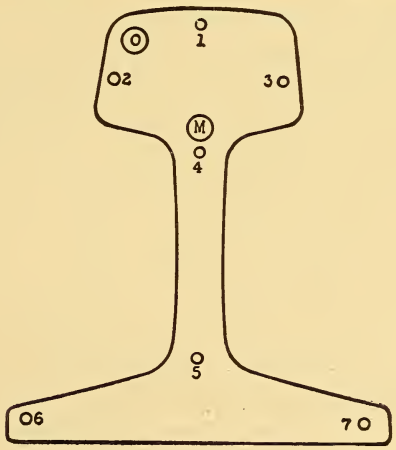


FIG. 3.—*Section of 100-pound P. S. rail, showing location of various* tests

Drillings for chemical analysis were taken at "O" and "M." Hardness determinations were made at the other positions indicated

3. RAILS

In the rail mill there are 6 passes in the roughing rolls, 4 in the intermediate rolls, and 1 finishing pass, making a total of 24 passes

from ingot to finished rail. The rails, which were Pennsylvania 100-pound section (Fig. 3), were cut at the hot saw as shown in Figs. 1 and 2.

The temperature of all rails was taken at the finishing pass. The rails were inspected for surface defects, piping, and discard to physically sound steel. The classification into "firsts" and "seconds" from surface conditions was made by the Pennsylvania Railroad Co. inspectors (Table 12); the discard to "physically sound steel" was made by cutting back in 5-foot lengths.

TABLE 12.—Classification of Rails Rolled from Sink-Head and Comparison Ingots [a]

Rails from sink-head ingots				Rails from comparison ingots			
Ingot number	B rail	C rail	D rail	B rail	C rail	D rail	E rail
1	1	2	1	1	1	1	2
2	1	1	1	1	1	1	1
3	1	2	1	1	1	1	1
4	2	2	2	1	1	1	1
5	(a)	2	2	1	1	1	2
6	2	2	2	1	1	1	1
7	2	2	2	1	1	1	1
8	2	2	2	1	1	1	1
9	1	1	2	1	1	1	1
10	2	1	2	(b)	1	1	1
11	2	2	2	1	1	1	2
12	2	1	2	1	1	1	1
13	2	2	2	(b)	2	1	1
14	1	1	1	(b)	1	1	1
15	2	2	2	1	1	1	1
16	2	2	2				
17	1	1	2				
18	1	1	1				
19	1	1	1				
20	2	2	2				
21	1	2	1				
22	1	1	1				
23	1	1	2				
24	1	1	1				
25	2	2	2				
26	1	1	1				
27	2	2	2				
28	2	2	2				
29	1	2	1				
30	2	2	2				
31	1	2	1				
32	2	2	2				
33	1	2	2				
34	2	2	2				
35	1	1	1				

		Per ct.
No. 1 rails	43	41
No. 2 rails	61	59
Total	104	100

		Per ct.
No. 1 rails	53	93
No. 2 rails	4	7
Total	57	100

[a] Inspection made by Pennsylvania Railroad Co. inspectors.
[b] Sent to Bureau of Standards.

The HA, the MX, and MA rails were held for tests to be described later. All pieces of rail were stamped to identify the ends.

4. TESTS

MECHANICAL TESTS.—The first sound 5-foot length obtained was taken as the drop-test piece. The test was made in the usual way by dropping a 2000-pound tup from a height of 18 feet upon the head of the rail which was supported at 2 points 3 feet apart. This test gives record of permanent set, elongation of the base, and the number of blows required for the destruction of the rail.

The 6-inch test pieces (B, C, D, etc., Figs. 1 and 2), the drop-test pieces, and the specimens from the MA position were examined for ultimate tensile strength, yield point, elongation (2-inch gage length), reduction of area, and hardness by Brinell and scleroscope. All specimens for the tension tests were cut longitudinally.

METALLOGRAPHIC TESTS.—There were taken of each test-piece section, a sulphur print, a light etching, and two photomicrographs at 100 diameters. Photomicrograph A was taken at upper part of web, B corresponds approximately with O position (Figs. 8 to 12, inclusive). These tests were also made on sections of the 5-foot pieces of the MX, MA, and HA rails to accompany the determinations of discard for chemical segregation.

CHEMICAL TESTS.—Determinations were made of the amounts of carbon, sulphur, phosphorus, manganese, and silicon at the "O" and "M" positions (Fig. 3) for test pieces (B, C, D, etc.) of all the rails; samples from the 5-foot pieces of MX, MA, and HA were also analyzed. Some specifications contain a clause which provides for the rejection of rails when the M position shows a carbon content more than 12 per cent greater (positive segregation) or more than 12 per cent less (negative segregation) than the O position. In the present investigation, all material showing more than 12 per cent positive or negative carbon segregation was considered as unavailable for rails. The railroad using this specification has found from experience that 12 per cent is the maximum safe limit of segregation.

III. DESCRIPTION OF OPERATIONS AND DISCUSSION OF RESULTS

1. INGOT PRACTICE

Since the sink-head ingots were cast in England and rolled in this country, they were necessarily subjected to the unusual process, at least in rail manufacture as ordinarily practiced, of reheating from the cold condition. The plan was considered of

allowing at least some of the comparison ingots to go "stone cold" and reheat them before rolling. However, in view of the fact that the ordinary type of ingot is not designed to meet this condition, which practically never obtains in practice and which, therefore, would be a possible misleading condition to impose on the comparison ingots and of no practical value, the comparison ingots were all rolled directly after being cast. These ingots were stripped from 20 to 30 minutes after casting and put into the soaking pits while still hot, where they remained from 1 hour and 40 minutes to 2 hours and 23 minutes.

The sink-head ingots after preliminary heating were charged into relatively cool pits (for temperature details see Section III, 2, Temperature Observations). The heat was gradually turned on after ½ hour and the ingots remained in the pits from 17⅓ hours to 21⅓ hours. The 35 sink-head ingots which were rolled were divided into three series and rolled on successive days, August 16, 17, 18, 1915. Three heats of comparison ingots were rolled, 1 on August 16 and 2 on August 18. There was no delay or other unusual condition in the mill during the rolling. The ingots of a group were rolled in succession, without intermission, and after the mill had been warmed up by rolling at least one complete heat of the regular product of the mill.

2. TEMPERATURE OBSERVATIONS

Temperature observations were taken of the soaking pits before, and at intervals, after immersion of ingots of both types; of all ingots in the blooming mill; and of rails from both series of ingots at the finishing pass. In order to heat them gradually, the Hadfield ingots lay on the surface of the soaking pits approximately 12 hours before charging. They were too hot to bear the hand comfortably when charged, at which time their estimated temperature was about 50° C (122° F). The pits which received these sink-head ingots were allowed to cool to the temperature of 600° C (1112° F)—750° C (1382° F) (Table 7). The immersion of the ingots further cooled the pits by some 200° C (392° F) as measured immediately after charging. The gas was turned on the pits ½ hour after charging. The comparison ingots were charged into the soaking pits hot, according to the usual practice.

Table 7 shows the values of the pit temperatures (1) before charging, (2) about 14½ hours after charging, and (3) just before drawing the sink-head ingots. These temperatures were taken with a platinum-rhodium thermocouple connected to a pivot

type of indicator. The couple was inclosed in nickel sheath except the tip, which was exposed. In some cases the temperatures were obtained by the use of an optical pyrometer of the Morse type.

By means of the optical pyrometer temperatures of the ingots were taken during the rolling. Average values obtained from 7 or 8 observations with optical pyrometer at alternate passes, after the first roughing pass, were taken of the ingots in the blooming mill. The temperature of the steel at the surface was lowered about 17° C (63° F) to 40° C (104° F) during the rolling into blooms. Typical illustrations of rolling temperatures are given in Table 9 for several ingots of both types. Table 7 contains finishing temperatures of Hadfield rail bars taken at the finishing pass by sighting on the center of base of rail bar with an optical pyrometer. Each observation is the average of two readings.

In Table 8 are similar data for the comparison ingots and rails, except that the pit temperatures were not taken. It will be noted that good uniformity of rolling and finishing temperatures was obtained.

A series of measurements was taken to compare the temperatures of this investigation taken at the finishing pass with those taken [3] at the hot saw by sighting on the head of the rail. The reading noted in Tables 7 and 8 of finishing temperatures should be reduced by about 11° C (52° F) to correspond to previous observations at hot saw.

The observed ingot and rail temperatures were taken on the outside oxidized surfaces, which are colder than the interior metal by 75° C (167° F) to 100° (212° F). This would account for the apparent discrepancy between the soaking-pit and ingot temperatures, and would make the average true finishing temperature somewhat higher than 1100° C (2012° F).

3. GENERAL COMPARISON OF THE TWO TYPES OF INGOT

(*a*) Size of Ingots.—The sink-head ingots were of 5200 pounds weight and the comparison ingots of 7300 pounds. In computing the percentage of ingot material available for rails the necessary constant valued deductions—i. e., the bottom-bloom crops and the middle and bottom rail crops—work to the relative disadvantage of the ingot of lesser weight. In was on this account that in Tables 10 and 11 the percentage of material available for

[3] B. S. Tech. Papers, No. 38, Observations on finishing temperatures and properties of rails.

rails is based upon both the original weight of ingot less the weight of the bottom-bloom crops and the initial weight minus the middle and bottom rail crops.

(*b*) Loss in Heating.—The sink-head ingots were weighed while cold before reheating, and the comparison ingots were weighed while hot. The abnormal loss in weight sustained by the former should be deducted from the nominal ingot weight in computing the net ingot. It so happens that the average bottom-bloom crop for the ingot made in an ordinary manner is 0.5 per cent greater than for the sink-head ingot; so that if the loss on heating for the comparison ingots is taken as 0.5 per cent there will be an exact balance. The English-cast ingots remained in the soaking pits some 10 times as long as the comparison ingots. If it is nevertheless preferred to compare actual percentages of material available for rails, that from the sink-head ingots should be increased by 2.5 per cent because there was a loss of 3 per cent, of which some 2.5 per cent can be charged to reheating. When this correction is made it is seen that the average sink-head ingot gives about 84.8 per cent material available for rails instead of 81.9 per cent. Ingot H24 should not be used in the discussion, as it was accidentally given an excessive bloom crop. The expression "material available for rails," as used here and in Tables 10 and 11, refers to only physically sound steel. Subsequent chemical analyses showed a much greater discard was necessary to eliminate segregation above 12 per cent (Tables 17 and 18).

(*c*) Comparison by Heats.—It will be noted that the three heats of comparison ingots have each very distinct characteristics; for example, as expressed in material available for rails, which are the results of varying open-hearth and casting practice. In group M1–M5 the percentage of material available for rails was 86.9 per cent; in group M6–M9, 85 per cent; and in group M11–M15, 65.8 per cent (Table 11). It was for this reason that, in addition to the general average of properties of all Maryland rails, averages were computed for each of the three Maryland heats. The three rollings of the Hadfield ingots show great uniformity, however expressed, and thus indicate that the manufacture of the ingots in all cases apparently was carried out in accordance with a uniform practice.

TABLE 13.—Mechanical and Chemical Characteristics of Rails from Sink-Head Ingots

Rail No.	Average, ADFM,[a] or DFAR [b]	Tension tests				Hardness		Elements determined (per cent)									
		Yield point	Ultimate strength	Elongation, per cent in 2 inches	Reduction of area	Brinell	Scleroscope	Carbon			Manganese		Phosphorus		Silicon		Sulphur	
								O	M	Segregation[c]	O	M	O	M	O	M	O	M
		Lbs. in.	Lbs. in.		Per cent													
HA	Average	62 074	125 986	14.5	23.48	259	33	0.652	0.733	+12.73	0.88	0.85	0.035	0.033	0.137	0.139	0.047	0.050
	ADFM [a]	1 585	2 342	0.7	1.25	6	1	.018	.044	7.84	.04	.03	.003	.002	.008	.007	.003	.005
	DFAR [b]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HB	Average	63 212	126 381	13.3	23.89	264	31	.649	.664	2.32	.89	.89	.032	.032	.139	.139	.047	.048
	ADFM	1 206	2 027	0.9	1.50	8	1	.016	.018	1.35	.03	.04	.002	.002	.011	.012	.004	.005
	DFAR	+1 138	+395	−1.2	+0.41	+5	−2	−.003	−.069	−10.41	+.01	+.04	−.003	−.001	+.002	0	0	−.002
HC	Average	62 941	126 054	13.6	24.30	260	31	.653	.644	− 1.27	.89	.88	.032	.031	.139	.138	.047	.046
	ADFM	1 109	2 130	0.7	1.18	9	1	.017	.017	1.68	.03	.04	.002	.002	.011	.012	.003	.003
	DFAR	867	+68	−0.9	+0.82	+1	−2	+.001	−.089	−14.00	+.01	+.03	−.003	−.002	+.002	−.001	0	−.004
HD	Average	63 029	126 158	13.6	24.47	260	30	.650	.621	4.48	.89	.88	.032	.031	.139	.137	.047	.044
	ADFM	1 310	2 381	0.7	1.14	7	1	.017	.022	1.81	.03	.03	.002	.002	.011	.012	.004	.004
	DFAR	+955	+172	−0.9	+0.99	+1	−3	−.002	−.112	−17.21	+.01	+.01	−.003	−.002	+.002	−.002	0	−.006
HE	Average	62 264	124 303	14.2	25.70	256	30	.637	.639	+ 0.40	.89	.88	.032	.037	.137	.137	.046	.046
	ADFM	1 418	2 900	0.6	1.63	10	1	.019	.023	1.42	.03	.04	.002	.003	.011	.011	.004	.004
	DFAR	+190	−1 683	−0.3	+2.22	−3	−3	.015	.094	12.33	+.01	+.03	−.003	−.001	0	−.002	−.001	−.004
	GENERAL AVERAGES																	
H	General averages	62 704	125 771	13.8	24.38	260	31	0.648	0.660	1.94	0.89	0.88	0.032	0.033	0.138	0.138	0.047	0.047
	ADFM	1 326	2 356	0.8	1.34	8	1	.017	.025	2.75	.03	.04	.002	.002	.010	.011	.004	.005

[a] Average deviation from mean.
[b] Deviation from A rail.
[c] Shows percentage carbon variation of M from O position.

TABLE 14.—Mechanical and Chemical Characteristics of Rails from Comparison Ingots

Rail No.	Average, ADFM[a] or DFAR[b]	Tension tests				Hardness		Carbon		
		Yield point	Ultimate strength	Elongation, per cent in 2 inches	Reduction of area	Brinell	Sclero-scope	O	M	Seg.[c]
		Lbs./in.²	Lbs./in.²		Per cent					
M1-5A	Average	60 721	120 960	13.5	23.16	246	32	0.601	0.736	+22.32
	ADFM[a]	821	2 928	1.0	3.23	5	1	.023	.056	6.65
M6-9A	Average	60 115	123 600	12.8	21.42	252	33	.652	.730	+11.88
	ADFM	885	1 075	1.0	1.61	8	0	.009	.045	6.04
M11-15A	Average	64 963	129 695	13.3	23.43	267	34	.682	.738	+ 8.52
	ADFM	1 322	1 226	0.2	1.50	7	1	.150	.058	9.60
M1-5B	Average	64 145	127 910	11.6	20.80	260	33	.641	.709	+10.60
	ADFM	1 048	2 048	0.5	1.61	3	1	.011	.041	4.78
M6-9B	Average	63 140	128 188	11.6	20.18	259	33	.675	.715	+ 6.18
	ADFM	238	938	0.6	1.20	6	1	.008	.095	1.51
M11-15B	Average	64 484	130 140	12.5	23.92	263	33	.661	.671	− 1.53
	ADFM	345	888	0.4	0.70	1	1	.070	.190	1.49
M1-5C	Average	61 752	124 290	12.5	24.18	244	32	.634	.613	− 3.40
	ADFM	411	548	0.4	0.57	7	1	.007	.030	4.09
M6-10C	Average	61 982	127 520	12.0	20.81	255	34	.673	.673	0.00
	ADFM	593	556	0.6	0.56	2	1	.011	.021	2.12
M11-15C	Average	62 415	126 850	13.1	26.77	354	32	.673	.646	− 4.02
	ADFM	704	1 720	0.5	0.71	3	1	.070	.050	0.89
M1-5D	Average	61 254	123 295	13.1	26.70	245	32	.635	.596	− 6.12
	ADFM	1 207	1 016	0.7	1.40	5	1	.011	.016	1.04
M6-10D	Average	61 158	125 700	12.5	23.75	246	31	.671	.635	− 5.43
	ADFM	686	940	0.4	0.50	2	0	.003	.009	1.56
M11-15D	Average	62 290	126 750	13.6	26.95	252	31	.674	.607	− 9.88
	ADFM	772	1 060	0.3	0.26	4	1	.080	.070	1.58
M1-5E	Average	59 233	120 465	14.7	30.40	240	31	.623	.534	−14.35
	ADFM	1 150	722	0.6	1.30	3	0	.003	.010	1.32
M6-10E	Average	59 000	123 055	13.9	26.72	246	33	.650	.617	− 4.99
	ADFM	446	874	0.4	1.44	2	1	.008	.013	2.15
M11-15E	Average	60 944	124 050	14.3	29.26	242	31	.643	.570	−11.40
	ADFM	1 372	1 020	0.4	0.55	6	1	.110	.110	1.25

M1-5F	Average	67 592	117 190	15.5	32.34	234	32	.585	.595	+ 1.73
	ADFM	500	1 048	0.6	0.59	8	1	.004	.033	6.07
M6-10F	Average	59 395	121 735	15.2	30.03	244	32	.637	.643	− 0.53
	ADFM	382	1 248	0.5	0.73	5	2	.007	.008	2.05
M11-15F	Average	59 450	120 065	15.8	32.68	249	32	.613	.611	− 0.39
	ADFM	1 028	1 502	0.2	0.82	2	0	.040	.080	1.42

SUMMARY BY INGOT POSITION

M-A rails	Average	62 063	124 834	13.2	22.76	255	33	0.644	0.735	+14.41
	ADFM	2 091	3 472	.6	2.14	11	1	.064	.045	7.53
	DFAR	0	0	0	0	0	0	0	0	0
M-B rails	Average	63 979	128 786	11.9	21.73	260	33	.665	.697	+ 5.00
	ADFM	840	1 488	.5	1.19	4	1	.032	.109	2.67
	DFAR	+ 1 916	+3 952	− 1.3	− 1.03	+ 5	0	+ .021	− .038	− 9.41
M-C rails	Average	62 050	126 220	13.5	23.92	251	33	.660	.644	− 2.42
	ADFM	631	1 606	.6	.61	6	1	.029	.034	2.35
	DFAR	− 13	+ 1 388	+ .3	+ 1.16	− 4	0	+ .016	− .091	−11.99
M-D rails	Average	61 567	125 248	13.1	25.80	248	31	.660	.612	− 7.14
	ADFM	999	1 495	.6	.72	4	1	.031	.032	1.39
	DFAR	− 496	+ 414	− .1	+ 3.04	− 7	− 2	+ .016	− .123	− 7.27
M-E rails	Average	59 726	122 523	14.3	28.79	243	32	.638	.573	−10.40
	ADFM	1 068	1 536	.5	1.09	5	1	.043	.044	1.57
	DFAR	− 2 337	− 2 311	+ 1.1	+ 6.03	− 12	− 1	− .006	− .162	− 4.01
M-F rails	Average	58 826	119 663	15.5	31.68	242	32	.611	.616	+ .27
	ADFM	1 052	2 049	.5	.71	8	1	.017	.040	3.18
	DFAR	− 3 237	− 5 179	+ 2.3	+ 8.92	−13	− 1	− .033	− .119	−14.14

SUMMARY BY HEATS

M1-5	Average	60 783	122 352	13.5	26.26	245	32	0.620	0.631	+ 1.80
	ADFM	1 873	3 068	1.2	3.53	9	1	.020	.064	10.84
M6-10	Average	60 757	124 792	13.1	24.03	250	33	.636	.665	+ .98
	ADFM	1 416	2 151	1.2	3.13	6	1	.024	.038	5.64
M11-15	Average	62 431	126 258	13.8	27.17	255	32	.661	.641	− 3.22
	ADFM	1 604	4 681	.7	2.62	3	1	.038	.042	5.14

GENERAL AVERAGE

	General average	61 368	124 545	13.6	25.78	250	32	0.645	0.646	+ 0.16
	ADFM	1 113	1 941	.6	1.01	6	1	.036	.051	3.12

[a] Average deviation from mean. [b] Deviation from A rail. [c] Shows percentage carbon variation of "M" from "O" position.

TABLE 14.—Mechanical and Chemical Characteristics of Rails from Comparison Ingots—Continued

Rail No.	Average, ADFM[a] or DFAR[b]	Manganese		Phosphorus		Silicon		Sulfur		Nickel		Chromium	
		O	M	O	M	O	M	O	M	O	M	O	M
M1-5A	Average	0.64	0.68	0.010	0.013	0.127	0.130	0.058	0.086	0.75	0.75	0.28	0.29
	ADFM[a]	.01	.02	.001	.001	.005	.006	.004	.015	.01	.01	.01	.01
M6-9A	Average	.66	.67	.015	.018	.142	.145	.096	.124	.72	.72	.29	.30
	ADFM	.01	.01	.000	.002	.007	.008	.007	.018	.00	.01	.00	.00
M11-15A	Average	.77	.79	.028	.032	.178	.179	.118	.117	.73	.73	.26	.27
	ADFM	.01	.02	.001	.004	.015	.018	.004	.029	.00	.01	.00	.00
M1-5B	Average	.68	.69	.012	.013	.129	.130	.074	.097	.77	.77	.28	.28
	ADFM	.01	.01	.000	.000	.007	.006	.004	.011	.01	.00	.00	.02
M6-9B	Average	.68	.68	.016	.018	.168	.147	.103	.115	.75	.75	.28	.28
	ADFM	.01	.01	.001	.001	.020	.002	.001	.006	.01	.01	.01	.01
M11-15B	Average	.78	.78	.030	.029	.174	.174	.122	.120	.73	.74	.27	.27
	ADFM	.01	.01	.001	.001	.007	.007	.001	.006	.00	.01	.01	.00
M1-5C	Average	.67	.67	.013	.012	.128	.128	.076	.073	.77	.78	.27	.28
	ADFM	.01	.00	.001	.001	.007	.006	.001	.005	.00	.01	.01	.01
M6-10C	Average	.66	.66	.017	.017	.145	.145	.101	.103	.74	.74	.26	.29
	ADFM	.01	.01	.000	.001	.004	.003	.001	.002	.01	.01	.01	.01
M-11-15C	Average	.78	.78	.029	.027	.173	.172	.118	.114	.74	.74	.27	.27
	ADFM	.01	.02	.000	.001	.008	.008	.003	.002	.00	.00	.01	.00
M1-5D	Average	.67	.66	.012	.016	.127	.145	.007	.094	.78	.74	.29	.29
	ADFM	.01	.01	.001	.001	.008	.001	.003	.004	.00	.01	.01	.01
M6-10D	Average	.67	.67	.016	.012	.144	.127	.100	.069	.74	.78	.29	.28
	ADFM	.00	.00	.001	.001	.002	.008	.002	.003	.00	.01	.01	.01
M11-16D	Average	.78	.78	.028	.027	.173	.172	.119	.108	.74	.74	.27	.26
	ADFM	.01	.00	.001	.001	.009	.006	.002	.003	.00	.01	.01	.01
M1-5E	Average	.67	.67	.012	.011	.130	.130	.073	.060	.77	.77	.28	.28
	ADFM	.01	.01	.001	.000	.006	.006	.001	.001	.00	.00	.01	.01
M6-10E	Average	.66	.66	.016	.016	.148	.147	.097	.090	.74	.75	.29	.28
	ADFM	.01	.00	.001	.001	.001	.001	.003	.003	.01	.00	.01	.00
M11-15E	Average	.78	.78	.028	.024	.175	.176	.114	.096	.74	.73	.27	.26
	ADFM	.01	.01	.001	.001	.010	.007	.001	.002	.00	.00	.00	.01
M1-5F	Average	.67	.65	.010	.011	.132	.133	.065	.070	.77	.77	.28	.28
	ADFM	.01	.02	.000	.001	.006	.006	.001	.005	.01	.01	.01	.01

M6–10F	Average	.66	.68	.016	.018	.147	.151	.096	.097	.73	.74	.29	.28
	ADFM	.00	.03	.001	.003	.002	.006	.003	.003	.01	.01	.01	.01
M11–15F	Average	.78	.77	.026	.026	.177	.178	.104	.106	.74	.73	.26	.26
	ADFM	.02	.01	.002	.000	.007	.007	.002	.001	.00	.00	.00	.00

SUMMARY BY INGOT POSITION—Continued

M–A rails	Average	0.69	0.71	0.018	0.021	0.149	0.152	0.091	0.106	0.73	0.73	0.28	0.29
	ADFM	.01	.02	.001	.002	.009	.010	.005	.020	0	.01	.00	.00
	DFAR	.00	0	0	.000	0	0	0	0	0	0	0	0
M–B rails	Average	.71	.71	.020	.019	.156	.150	.099	.110	.75	.75	.28	.27
	ADFM	.01	.01	.001	.001	.010	.005	.002	.008	.01	.01	.01	.01
	DFAR	+ .02	0	+.002	+.002	+.007	−.002	+.008	+.004	+ .02	+ .02	.00	− .02
M–C rails	Average	.70	.70	.019	.019	.149	.148	.098	.096	.75	.75	.27	.28
	ADFM	.01	.01	.000	.001	.006	.006	.001	.002	.00	.01	.01	.01
	DFAR	+ .01	− .01	+.001	+.002	.000	−.004	+.007	−.010	+ .02	+ .02	− .01	− .01
M–D rails	Average	.71	.70	.019	.018	.148	.148	.099	.090	.75	.75	.28	.27
	ADFM	.01	.00	.001	.001	.006	.006	.002	.003	.00	.01	.01	.01
	DFAR	+ .02	− .01	+.001	−.003	−.001	−.004	+.008	−.016	+ .02	+ .02	0	− .02
M–E rails	Average	.70	.71	.019	.017	.150	.151	.095	.082	.75	.75	.28	.27
	ADFM	.01	.01	.001	.001	.005	.005	.002	.002	.00	.00	.01	.01
	DFAR	+ .01	.00	+.001	−.004	+.001	−.001	+.004	+.024	+ .02	+ .02	.00	− .02
M–F rails	Average	.70	.70	.017	.018	.152	.154	.088	.091	.74	.75	.28	.27
	ADFM	.01	.02	.001	.001	.005	.009	.002	.003	.01	.01	.01	.01
	DFAR	+ .01	− .01	−.001	−.003	+.003	+.002	−.003	−.015	+ .01	+ .02	.00	− .02

SUMMARY BY HEATS—Continued

M1–5	Average	0.67	0.67	0.012	0.012	0.129	0.130	0.071	0.076	0.77	0.77	0.28	0.28
	ADFM	.01	.01	.001	.001	.007	.007	.006	.012	.01	.01	.01	.01
M6–10	Average	.66	.65	.016	.017	.146	.147	.098	.103	.74	.74	.29	.29
	ADFM	.01	.02	.001	.001	.003	.004	.004	.010	.01	.02	.01	.01
M11–15	Average	.78	.78	.028	.027	.175	.175	.116	.114	.74	.74	.26	.27
	ADFM	.01	.01	.001	.001	.009	.009	.005	.002	.01	.01	.01	.01

GENERAL AVERAGE—Continued

	General average	0.70	0.71	0.019	0.019	0.151	0.151	0.095	0.096	0.75	0.75	0.28	0.28
	ADFM	.01	.001	.001	.001	.007	.007	.002	.006	.00	.01	.01	.01

[a] Average deviation from mean. [b] Deviation from A rail.

(*d*) INSPECTION OF INGOTS.—The sink-head ingots were examined while cold for surface defects, and the surface condition of all ingots was noted by another observer as they passed through the blooming mill (Tables 4 and 5). There were side splashes, rough sides, and rough corners on nearly all the sink-head ingots, and only 4 of the 35 were noted as clean blooms in rolling, as compared with 8 clean blooms from the 15 comparison ingots.

(*e*) COMPARISON OF CHEMICAL COMPOSITION. (1) *Sink-Head Ingots* (Table 13).—The chemical composition of the rails from the sink-head ingots shows a remarkable degree of uniformity. Thus for the O analysis the average carbon is 0.648 per cent, with an average deviation from mean of 0.017. If we take the C test piece as representing the ingot composition, the average for carbon of C–M is 0.644 per cent and C–O 0.653 per cent, the average deviation from mean in each case being 0.017.

The average phosphorus content of the O position is 0.032 per cent, with an average deviation of 0.002; for sulphur (O position) the average is 0.047 per cent, with a deviation of 0.004. For the M position the concordance is somewhat less good. Manganese and silicon are very uniformly distributed.

(2) *Comparison Ingots* (Table 14).—These ingots were cast with small end uppermost, and, except for a nickel content of 0.75 per cent and chromium content of 0.28 per cent, were of a composition and uniformity comparable with the sink-head type, the average O position having a carbon content of 0.645 per cent (sink head 0.648 per cent), with an average deviation from mean of 0.036. The manganese content is 0.70 per cent, as compared with 0.89 per cent for the sink-head ingots; the phosphorus content is 0.019 per cent, while in the sink-head ingot it is 0.047 per cent. Group M11–M15 has an average phosphorus content of 0.028 per cent, which quite closely agrees with that of English-cast ingots. This subgroup is also from its method of manufacture the best to compare with the imported ingots.

The sulphur content of the comparison ingots follows the grouping by heats; the O analysis of C rail, for example, for M1–M5 has a sulphur content of 0.076 per cent; for M6–M10 the sulphur is 0.101 per cent; for M11–M15 the sulphur is 0.118 per cent. The manganese and silicon of the first two groups are practically identical, while both are slightly higher in the third group (M11–M15). The chromium and nickel contents are practically constant at 0.28 per cent for the former and 0.75 per cent for the latter for all three groups.

4. THE SINK-HEAD INGOTS, THEIR MANUFACTURE AND CLASSIFICATION

There were 37 ingots of this Hadfield type cast large end up and each provided with a sink head (Table 1 and Fig. 4). The ingots were fed by the Hadfield method in the usual manner, with charcoal and blast continued for about 20 to 40 minutes until the molten steel had set on the top of the head.

FIG. 4.—*Sink-head ingot*

The steel was made by the converter process, a small furnace being used, and each ingot represents a heat. These ingots are of remarkable uniformity of chemical composition, weight, and sink-head characteristics (Table 2). About 30 to 40 seconds were required for pouring each ingot.

(*a*) SINK-HEAD EFFECT.—Due to the uncertainty of the location of the sink-head junction, an arbitrary allowance has to be made in advance at hot saw or shears or one risks having the A rails rejected. If the total top discard (bloom and rail) is adjusted to 13 per cent there will be no rails rejected on account of sink head; if this is set at 8 per cent one would expect about one-half the A rails to contain surface imperfections caused by the sink head and ingot junction (Table 10). The sink head alone entails on the average a discard of about 9.1 per cent of the Hadfield ingot.

The ingot usually enters the rolls with large end and sink head first; it appears, however, to make no difference which end of ingot is first subjected to the "squaring-up" pass. The presence of the sink head appears to present no difficulties in either the blooming mill or rail mill. One ingot cracked at the bottom of the sink head during rolling, but this was without effect on the passage of this bloom through the rolls.

(*b*) Piping in Sink-Head Ingots.—Two of the 35 sink-head ingots were examined as rails had pipes, detected in the mill, extending into the ingot 10 or 11 per cent, or to some 5 per cent below the sink head in some cases (Table 10). All piping would appear to be eliminated with a discard of 11 per cent, which is very nearly that required to eliminate all sink-head imperfections and carbon segregation above 12 per cent.

(*c*) Influence of Surface Condition of Ingots on Rail Classification.—It was possible to make a very careful examination for flaws in the surfaces of the sink-head ingots while cold; their condition during rolling, as well as of the comparison ingots, was also noted. In this way some idea of the relation of "second" rails to ingot surface may be established (Tables 4, 5, and 12).

There were a relatively large number of "second" rails from the sink-head ingots, 61 out of a total of 104 rails, or 59 per cent. There were only 4 in 57 from the comparison ingots, or 7 per cent. The A rails were not included for either group. This inspection was made by Pennsylvania Railroad Co. inspectors.

There appears to be no reason why ingots of the sink-head type should not be as well surfaced as any other, and the high percentage of seconds should not be attributed to the type of ingot, as the bottom of the sink head was well within the A rail, which was not classified. Probably the severe and unusual reheating conditions, together with the original surface as influenced by condition of the molds and teeming practice, contributed somewhat toward producing the large number of "seconds" from the sink-head ingots. A large percentage of "seconds" was similarly obtained from the reheated Hadfield ingots reported on by Hadfield and Burgess.[4]

5. THE COMPARISON INGOTS, THEIR MANUFACTURE AND CLASSIFICATION

There were 15 Maryland ingots, in 3 groups of 5 each, of about 7300 pounds each, top-poured into ingot molds with small end

[4] See footnote 1.

up. (See Table 1 for dimensions.) They were rolled as portions of three heats on different dates, the total number of ingots in a heat being 13 or 20. The time of teeming into molds was about 35 seconds each. The product from each heat thus forms a distinctive group and should be considered separately. The ingots were selected arbitrarily before being cast as the five to be poured in succession after the second one of the heat. The heats were three of a series of rail steel from the ordinary output of the open hearth and were not especially chosen.

The first 10 ingots, heats 2×4497 (M1–M5) and 1×3632 (M6–M10) were apparently made from rising steel, while ingots M11–M15 of heat 2×4510 were from quiet or "killed" steel; ingots M6–M15 were deoxidized with aluminum; ingots M1–M10 were chilled on top, M1–M5 with cast-iron caps and M6–M10 with water.

The effects of these differences in furnace and casting practice are very striking on the finished product. Thus the deoxidized flat-top ingots (M11–M15) show, as would be expected, pronounced piping; for this group the average discard to physically sound steel is 26.5 per cent and ranging from 8.5 to 39.5 per cent. With this discard may be compared the discard of 5.2 per cent for the first Maryland group and 8 per cent for the second, and except in 2 cases out of 35 a negligible discard for piping below the sink head of the Hadfield ingots. The small discard (6.6 per cent) to sound steel for the average of the first two Maryland groups is, however, misleading, as there may exist internal or inclosed pipes, especially for the second or deoxidized group. In the first comparison group (M1–M5) one would expect to find a spongy, segregated structure in the upper part of the ingot. This is brought out in some of the sulphur prints of rail from the upper part of the ingots of this group, a typical one being shown in Fig. 8.

Of the first group, M5 contains a very pronounced pipe near the bottom of the ingot in the F position (Fig. 9). The question may be raised as to whether the practice of chilling the ingot top does not tend to produce internal pipes which may be distributed anywhere along the center line of the ingot.

The phenomenon of segregation, which is intimately allied to the furnace and casting practice for the comparison ingot, is discussed separately. The mechanical properties, as brought out by the several tests—ultimate strength, yield point, elongation,

reduction of area, hardness and drop test—show less dependence on the processes of manufacture.

6. COMPARISON OF CHEMICAL SEGREGATION OF INGOTS OF BOTH TYPES

Each comparison ingot furnished 6 and each sink-head ingot 4 rails. In comparing the segregation of the A test piece it should be remembered that for the sink-head ingots this position is that of the drop-test piece at about 9 per cent below the top (including sink head), while for the comparison ingots the A test piece is at the junction of the X and A rails, or at 10.6 per cent from the top of ingot. Therefore they are in sufficiently similar positions for comparison, except that 10.6 per cent of a comparison ingot (7260 pounds) represents 770 pounds of steel, or 23 feet of rail, while 9.6 per cent of a sink-head ingot (5300 pounds) represents 509 pounds, or only 15 feet of rail, or the A position in the comparison has a rail discard 8 feet greater than the sink-head ingot on the average.

The E position of the rails from sink-head ingots should be compared with the position of the comparison ingots F, the sink head D with comparison E, the sink head C with comparison C and D, and the sink head B with comparison B.

For both types of ingot the longitudinal segregation of carbon is very slight along the O positions, while for the M positions, or along the center line of the ingot, it is quite marked, the carbon being greatest at A near the top of the ingot, decreasing to the H–D (or M–E) position, and rising again as the bottom of the ingot is approached. The results given are for the three types of comparison ingot, but for this effect, the type of ingot appears to be less important than for other factors.

The segregation of the sink-head ingots and of the three groups of ingots made with small end uppermost are discussed separately with reference to influence and method of manufacture.

(*a*) Segregation in Sink-Head Ingots.—The sink-head ingots were of "piping" steel deoxidized with aluminum. Each represents a separate heat of converter steel.

These ingots were in general of remarkable uniformity as regards segregation (Table 15), thus showing the furnace and casting practice also to have been very uniform. At the A test piece, 9.1 per cent below the top of the ingot on the average, the segregation, though variable, is always positive; that is, the carbon content of the M position is greater than that of the O position. Fourteen of

35 ingots have a segregation greater than 12 per cent and 3 greater than 25 per cent; for one of these (H13), the A position is only 5.1 per cent below the top of the ingot (Table 10).

For these 35 sink-head ingots the discard for segregation above 12 per cent is located 13 per cent (plus or minus 1.86) below top of ingot, with a maximum of 17.5 per cent and a minimum of 5.1 per cent (Tables 10 and 17).

TABLE 15.—Percentage Carbon Segregation in Rails from Sink-Head Ingots

Ingot	Rail A	Rail B	Rail C	Rail D	Rail E	Ingot	Rail A	Rail B	Rail C	Rail D	Rail E
H1	13.02	−0.15	−3.75	−4.59	1.23	H21	11.91	1.66	−0.75	0.45	2.61
H2	9.44	.00	−2.67	−6.77	−1.60	H22	2.67	− .75	.31	−3.48	− .30
H3	11.65	−5.33	−3.89	−7.42	− .79	H23	24.35	.77	−1.69	−4.09	−1.42
H4	16.49	4.83	−3.82	−3.41	− .62	H24	21.94	−2.26	−2.88	−2.93	−4.55
H5	.....	.....	−1.29	−1.30	− .44	H25	5.17	2.68	1.52	−2.56	2.73
H6	9.25	4.86	−1.73	−6.40	2.78	H26	34.16	.60	−1.22	−7.11	.92
H7	19.79	.30	−1.95	− .15	− .60	H27	4.76	1.38	.00	−4.48	3.09
H8	3.34	1.68	− .15	−5.20	1.57	H28	26.77	2.97	−3.12	−5.43	.16
H9	23.77	4.87	−1.12	−6.20	− .34	H29	10.50	3.58	−1.72	−7.55	.49
H10	20.63	2.17	.31	−4.54	3.09	H30	15.57	2.54	− .47	−4.32	− .97
H11	4.69	3.74	.32	−5.16	.32	H31	12.89	2.95	.31	−3.70	.62
H12	2.16	1.44	−2.41	−6.52	− .57	H33	3.83	2.06	−7.41	−2.68	.60
H13	46.69	−3.11	−4.35	−1.27	−2.79	H34	10.11	6.75	−2.72	−5.16	−2.96
H14	2.48	1.49	.00	−4.32	.30	H35	10.33	3.32	−5.11	−6.16	1.46
H15	7.83	4.08	−4.63	1.18	1.63	H36	15.48	2.37	2.54	−4.59	− .96
H16	13.93	4.52	−2.33	−9.74	−1.41	Average	+12.73	+2.32	−1.27	−4.48	+0.40
H17	1.50	4.75	1.22	−5.33	3.29	ADFM[a]	7.48	1.35	1.68	1.81	1.42
H18	5.20	1.96	− .30	−3.46	2.14						
H19	9.66	2.85	.00	−7.28	.81						
H20	1.04	2.60	−1.96	−5.07	1.73						

[a] Average deviation from mean.

TABLE 16.—Percentages Carbon Segregation in Rails from Comparison Ingots

Ingot	Rail A	Rail B	Rail C	Rail D	Rail E	Rail F
M1	30.88	7.17	−8.80	− 5.07	−12.34	−13.45
M2	30.39	27.55	.31	− 7.73	−13.06	3.93
M3	13.30	9.63	.96	− 5.79	−15.20	4.44
M4	20.17	5.28	−8.23	− 4.41	−15.89	2.96
M5	16.85	3.37	−1.25	− 7.61	−15.24	10.75
M6	16.51	9.20	−4.98	− 5.93	− 3.71	.62
M7	19.34	5.07	3.68	− 3.44	− 8.79	.00
M8	2.51	5.05	.91	− 5.76	− 6.65	.64
M9	9.15	5.38	.73	− 8.27	− 1.42	− 5.91
M10	.....	.....	− .31	− 3.73	− 4.41	.....
M11	3.08	− .87	−4.95	− 8.69	−11.78	− 1.16
M12	32.52	−1.61	−3.61	−11.00	−11.68	− 2.08
M13	.....	−1.98	−5.31	− 7.12	−13.82	− 1.47
M14	4.74	−6.26	−2.48	−11.92	− 8.62	.16
M15	.15	3.07	−3.73	−10.66	−11.09	2.61
Average	+14.41	+5.00	−2.42	−7.14	−10.40	+ .27
ADFM[a]	7.53	2.67	2.35	1.39	1.57	3.18

[a] Average deviation from mean.

At A the average segregation is +12.73 per cent, ±7.48; at B the segregation is +2.32, ±1.35, with only 4 negative values; at

C it is −1.27 per cent, ±1.66, with 10 positive values; at D it is 4.48 per cent, ±1.81, with only 2 positive values; and at E only +0.40 per cent, ±1.42, with 15 negative values (Table 15).

(*b*) SEGREGATION IN COMPARISON INGOTS. (1) *Group M1–M5 (Heat 2×4497)*.—This heat has no aluminum addition in molds, and cast-iron caps were put on the tops of the ingots as soon as poured. It was found that the ingot tops were rounded after the steel had solidified; therefore, they were made of rising steel not specially deoxidized in the mold. The ingots were stripped 20 minutes after casting and remained in soaking pits from 2 hours and 10 minutes to 2 hours and 23 minutes. This is about as rapid handling of ingots in the molds as it is possible to have, although the time in pits could have been lessened. The resulting composition and segregation is strikingly characteristic of their history.

TABLE 17.—Necessary Total Discard (Percentage) in Rails from Sink-Head Ingots [a]

[H24 was omitted, as this ingot was given an excessive bottom crop due to error in judgment at mill. *s*=discard for segregation. *p*=discard for physical unsoundness.]

Ingot number	Top	Bottom (*p*)	Middle (*p*)	Chemical	Physical	Total
H1	*s* 16.2	3.0	1.8	16.2	4.8	21.0
H2	*s* 12.3	2.5	1.8	12.3	4.3	16.6
H3	*s* 13.9	3.4	2.6	13.9	6.0	19.9
H4	*s* 17.5	3.4	1.8	17.5	5.2	22.7
H6	*s* 13.4	3.7	1.9	12.4	5.6	18.0
H7	*s* 14.0	3.7	2.1	14.0	5.8	19.8
H8	*s* 12.1	3.9	2.4	12.1	6.3	18.4
H9	*s* 15.0	4.2	2.3	15.0	6.5	21.5
H10	*s* 15.6	3.6	2.0	15.6	5.6	21.2
H11	*s* 14.3	3.7	2.1	14.3	5.8	20.1
H12	*p* 10.7	4.1	2.1	.....	16.9	16.9
H13	*s* 13.0	3.8	1.8	13.0	5.6	18 6
H14	*s* 13.8	3.8	1.9	13.8	5.7	19.5
H15	*s* 12.6	3.3	2.2	12.6	5.5	18.1
H16	*s* 12.4	4.4	1.7	12.4	6.1	18.5
H17	*p* 9.1	4.0	2.4	.....	15.5	15.5
H18	*s* 13.9	3.9	2.4	13.9	6.3	20.2
H19	*s* 11.8	3.6	1.9	11.8	5.5	17.3
H20	*s* 14.0	3.7	2.1	14.0	5.8	19.8
H21	*s* 14.6	3.6	2.3	14.6	5.9	20.5
H22	*s* 11.5	3.4	1.8	11.5	5.2	16.7
H23	*s* 10.6	4.3	2.4	10.6	6.7	17.3
H25	*p* 9.4	4.2	2.3	.....	15.9	15.9
H26	*s* 14.3	3.8	1.9	14.3	5.7	20.0
H27	*s* 9.7	3.2	2.5	9.7	5.7	15.4
H28	*s* 13.8	2.7	2.0	15.8	4.7	8.5
H29	*s* 16.8	3.8	2.0	16.8	5.8	22.6
H30	*p* 9.8	4.3	2.3	.....	16.4	16.4
H31	*p* 8.8	3.0	1.6	.....	13.5	13.5
H33	*s* 12.5	4.6	2.4	12.5	7.0	19.5
H34	*s* 14.4	4.2	1.9	14.4	6.1	20.5
H35	*s* 11.6	4.0	1.8	11.6	5.8	17.4
H36	*s* 15.9	3.9	1.9	15.9	5.8	21.7
Average	13.0	3.7	2.1	11.5	7.2	18.4
Deviation	1.86	.....	.....	.....	.....	.....

[a] The total discard (top, middle, and bottom) includes the discard necessary to eliminate piping and segregation above 12 per cent.

TABLE 18.—Necessary Total Discard (Percentage) in Rails from Comparison Ingots [a]

[*s*=discard for segregation. *p*=discard for physical unsoundness. B, E, D refer to rails having above 12 per cent segregation or having inclosed pipes.]

Ingot number	Top	Bottom	Middle	Chemical	Physical	Total
M1	*s* 31.9	*p* 4.7	*s* 32.0 E+D	63.9	4.7	68.6
M2	*s* 24.8	*p* 4.3	*s* 34.5 B+E+D	59.3	4.3	63.6
M3	*s* 23.9	*p* 3.1	*s* 34.4 E+D	58.3	3.1	61.4
M4	*s* 23.7	*p* 3.7	*s* 34.5 E+D	58.2	3.7	61.9
M5	*s* 28.6	*p* 3.3	*ps* 33.7 E+D	62.3	3.3	66.6
Average	26.6	3.4	33.8	60.4	3.8	64.2
M6	*s* 25.3	*p* 5.0	*p* 1.5	25.3	6.5	31.8
M7	*s* 23.7	*p* 3.9	*p* 1.3	23.7	5.2	28.9
M8	*s* 23.3	*p* 4.0	*p* 1.6	23.3	5.6	28.9
M9	*s* 23.8	*p* 4.8	*p* 1.1	23.8	5.9	29.7
Average	24.0	4.44	1.4	24.0	5.8	29.8
M11	*p* 29.0	*p* 5.1	*p* 1.6	0	35.7	35.7
M12	*s* 19.8	*p* 5.0	*p* 1.7	19.8	6.7	26.5
M13	*p* 39.5	*p* 4.1	[b] *p* 1.0	0	44.6	44.6
M14	*p* 28.2	*p* 4.6	[b] *p* 1.6	0	34.4	34.4
M15	*p* 27.4	*p* 4.8	[b] *p* 1.9	0	34.1	34.1
Average	26.8	4.7	1.6	4.0	31.1	35.1
Average	26.0	3.8	13.0	30.0	14.1	43.9
Deviation	±3.3	.....	.....	.....	.....	.....

[a] The total discard (top, middle, and bottom) includes the discard necessary to eliminate piping and segregation above 12 per cent.

[b] M13 and M14 contain trace of piping in B position. M15 has a small pipe at F.

The top of the ingot is characterized by high and variable segregation; thus the total top discard required to eliminate segregation above 12 per cent ranged from 23.7 to 31.9 per cent for the five ingots, as compared with a top discard of 2.6 to 9.3 per cent to the physically sound steel; that is, free from pipe (Tables 11 and 18). Within this range of discard for segregation, however, the segregation in a single ingot varied by enormous amounts, such as 26.52 to 94.62 per cent for ingot M2 and −7.36 to 49.28 per cent for ingot M5 (Table 20). This type of ingot is also characterized in all cases, by high negative segregation in the lower portion of the ingot, particularly marked at the E position, where it ranges from −12.34 per cent to −15.89 per cent (Table 16). Except for M1, at the bottom of the ingot F position (−13.45 per cent, Table 16), there is a reversal to relatively small positive segregation. All but M2 contain a well-marked soft streak at F, the bottom of the ingot, and in the case of M5 this streak incloses a pronounced pipe (Figs. 9 and 10). The total material that should be discarded from this type of ingot for segregation ranges from 58.2 to 63.9 per cent (Table 18). Provision should be made for a larger bottom-bloom crop than is customary to eliminate both segregation and piping in the bottom of the ingot. The bottom

rail and the adjacent one from every ingot of this group (M1–M5) should be discarded for segregation. The bottom rail has in addition elements of physical weakness shown by the soft steel streaks which may inclose pipes.

(2) *Group M6–M10* (*Heat 1×3632*).—The ingots of this heat had rounded tops on which water was put a few moments after casting; they were also treated while being cast with 2 ounces of aluminum per ton of steel. They were, therefore, of rising steel deoxidized in the molds, and should show somewhat greater tendency to piping than the first group; this is borne out by the results. The ingots of the second group required a discard averaging 8 per cent on account of pipe, while only one of the first group required a discard in excess of this amount (Table 11).

With respect to the B, C, D, E, and F positions for this group, the segregation is relatively low (max., 9.20 per cent, Table 16) and uniform from one ingot to another, as well as within any particular ingot, downward from the B position. The top discard for carbon segregation greater than 12 per cent (in O and M positions) is 23.3 to 25.3 per cent (Table 18), and within this discard the segregation is less extreme than in ingots of the first group, the maximum being about 25 per cent, which obtained in only 2 positions out of 29 (Table 20).

(3) *Group M11–M15* (*Heat 2×4510*).—Two ounces of aluminum per ton were added to the ingots M11–M15 for the purpose of deoxidation. The ingot tops, which were flat after pouring into molds, were not chilled with caps or water. These ingots were, therefore, of quiet, piping steel and apparently more nearly approach the type of steel represented by the sink-head ingots than do the other two groups of comparison ingots. They remained somewhat longer in the molds (30 minutes as compared with 20 and 23 minutes) before stripping, and slightly longer in the soaking pits than the other comparison ingots.

The considerable piping at the top of the ingots of this group is very strikingly characteristic of the above open-hearth and casting practice. The carbon segregation in the upper half and at the bottom of this type of ingot is slight, but there is developed negative segregation ranging about 11 per cent at the D and E positions (Table 16). In contrast to the other two types of Maryland ingot the extent of the top discard is determined (Table 18), except for M12, which shows other anomalies, by piping (average discard 26.8 per cent) rather than by segregation (average discard 16.4 per cent, Table 22). The metallographic examination shows

a small pipe in rail M15 at the bottom of the ingot in the F position, and incipient piping in M13 and M14 at the B position.

TABLE 19.—Percentage Segregation of Carbon in the "A" Rails of Sink-Head Ingots [a]

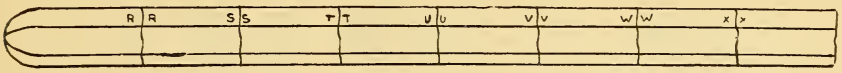


Diagram of cutting up of "A" rail of sink-head ingots

Ingot	Carbon	R	S	T	U	V	W	X
H1	Carbon O	0.632	0.649	0.647	0.650	0.658	0.648	0.647
	Carbon M	.902.	.789	.732	.683	.673	.674	.673
	Segregation	42.72	21.57	13.14	/ 5.08	2.28	4.01	4.02
H2	Carbon O	.610	.636	.635	.632	.634	.637	.636
	Carbon M	.967	.804	.705	.690	.659	.653	.654
	Segregation	58.52	26.42	/ 11.02	9.18	3.94	2.51	2.83
H3	Carbon O	.657	.670	.667	.653	.657	.....	.....
	Carbon M	.746	.708	.674	.682	.673	.....	.....
	Segregation	13.55	/ 5.67	1.05	4.44	2.44	.....	.....
H4	Carbon O	.605	.657	.654	.655	.649	.656	654
	Carbon M	.719	.777	.767	.708	.719	.691	.674
	Segregation	18.84	18.26	17.28	/ 8.09	10.79	5.34	3.06
H6	Carbon O	.640	.641	.641	.643	.644	.....	.....
	Carbon M	.805	.697	.675	.676	.674	.....	.....
	Segregation	25.78	/ 8.74	5.30	5.13	4.66	.....	.....
H7	Carbon O	.630	.669	.647	.667	.663	.662	.661
	Carbon M	.727	.889	.715	.686	.676	.671	.669
	Segregation	15.40	32.88	/ 10.51	2.85	1.96	1.36	1.21
H8	Carbon O	.649	.656	.657	.659	.654	.657	.....
	Carbon M	.758	.690	.673	.661	.662	.664	.....
	Segregation	16.80	/ 5.18	2.44	.30	1.22	1.07	.....
H9	Carbon O	.655	.662	.642	.639	.640	.649	.....
	Carbon M	.804	.742	.686	.658	.662	.674	.....
	Segregation	22.75	12.08	/ 6.85	2.97	3.44	3.85	.....
H10	Carbon O	.661	.638	.638	.643	.653	.643	.....
	Carbon M	.727	.717	.669	.667	.667	.660	.....
	Segregation	9.98	12.38	/ 4.86	3.73	2.14	2.64	.....
H11	Carbon O	.639	.643	.638	.636	.638	.620	.....
	Carbon M	.733	.674	.637	.653	.659	.655	.....
	Segregation	14.71	/ 4.82	.16	2.67	3.29	5.65	.....
H12	Carbon O	.700	.701	.695	.699	.712	.....	.....
	Carbon M	.743	.713	.712	.707	.702	.....	.....
	Segregation	16.14	1.71	2.45	1.14	—1.40	.....	.....
H13	Carbon O	.627	.645	.649	.657	.642	.651	.656
	Carbon M	.786	.739	.664	.667	.658	.666	.663
	Segregation	25.36	14.57	/ 2.31	1.52	2.49	2.30	1.07
H14	Carbon O	.655	.676	.692	.687	.683	.692	.682
	Carbon M	.839	.775	.711	.703	.693	.698	.696
	Segregation	28.09	14.64	/ 2.75	2.33	1.46	.87	2.05
H15	Carbon O	.691	.692	.696	.693	.689	.684	.....
	Carbon M	.758	.819	.761	.725	.719	.713	.....
	Segregation	9.70	18.35	/ 9.34	4.62	4.35	4.24	.....
H16	Carbon O	.685	.687	.693	.674	.683	.....	.....
	Carbon M	.776	.731	.689	.706	.715	.....	.....
	Segregation	13.28	/ 6.40	— .58	4.75	4.69	.....	.....
H17	Carbon O	.667	.675	.669	.657	.659	.659	.....
	Carbon M	.699	.705	.686	.688	.670	.687	.....
	Segregation	/ 4.80	4.44	2.54	4.72	1.67	4.25	.....

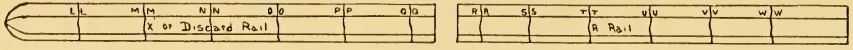
[a] The rails were broken at about 5-foot intervals for analysis in accordance with diagram to determine the top discard necessary to eliminate carbon segregation above 12 per cent. The point at which the segregation becomes less than this amount is indicated by "/" in the table.

[b] H25 ingot { Carbon { O ... 0.590; M .. .702 } Segregation .. 18.98 }

TABLE 19—Percentage Segregation of Carbon in the "A" Rails of Sink-Head Ingots—Continued

Ingot		R	S	T	U	V	W	X
H18	Carbon O	0.672	0.672	0.672	0.662	0.676	.....	.....
	Carbon M	.771	.772	.712	.692	.669	.....	.....
	Segregation	14.73	14.88	/ 5.95	4.53	−1.04	.....	.....
H19	Carbon O	.634	.631	.635	.631	.632	.....	.....
	Carbon M	.732	.701	.655	.654	.656	.....	.....
	Segregation	15.46	/ 11.09	3.15	3.65	3.80	.....	.....
H20	Carbon O	.638	.661	.663	.660	.668	.....	.....
	Carbon M	.752	.686	.689	.684	.679	.....	.....
	Segregation	17.87	/ 3.78	3.92	3.64	1.65	.....	.....
H21	Carbon O	.676	.674	.680	.668	.679	.....	.....
	Carbon M	.809	.707	.708	.692	.697	.....	.....
	Segregation	19.67	/ 4.90	4.12	3.59	2.65	.....	.....
H22	Carbon O	.678	.671	.671	.674	.681	.....	.....
	Carbon M	.725	.680	.682	.688	.707	.....	.....
	Segregation	/ 6.93	1.34	1.64	2.08	3.82	.....	.....
H23	Carbon O	.644	.655	.646	.647	.644	.....	.....
	Carbon M	.790	.703	.673	.669	.665	.....	.....
	Segregation	22.67	/ 7.33	4.18	3.40	3.26	.....	.....
H24	Carbon O	.618	.628	.629	.626	.....	.....	.....
	Carbon M	.835	.791	.698	.657	.....	.....	.....
	Segregation	35.11	25.96	/ 10.97	4.95	.....	.....	.....
H25	Carbon O	.596	.596	.599	.599	.591	.....	.....
	Carbon M	.633	.627	.625	.609	.609	.....	.....
	Segregation	/ 6.21	5.20	4.34	1.67	3.05	.....	.....
H26	Carbon O	.657	.665	.658	.665	.660	0.661	.....
	Carbon M	.858	.760	.714	.685	.678	.689	.....
	Segregation	30.59	14.29	/ 8.51	3.01	2.73	4.24	.....
H27	Carbon O	.655	.666	.654	.661	.650	.643	.....
	Carbon M	.722	.707	.662	.669	.656	.666	.....
	Segergation	/ 10.23	6.16	1.22	1.21	.92	3.58	.....
H28	Carbon O	.642	.645	.657	.647	.649	.647	.....
	Carbon M	.749	.746	.689	.673	.665	.666	.....
	Segregation	16.67	15.66	/ 4.87	4.02	2.47	2.94	.....
H29	Carbon O	.650	.646	.638	.654	.644	.....	.....
	Carbon M	.754	.682	.667	.671	.668	.....	.....
	Segergation	16.00	/ 5.57	4.55	2.60	3.73	.....	.....
H30	Carbon O	.626	.637	.631	.636	.635	.....	.....
	Carbon M	.681	.666	.662	.661	.656	.....	.....
	Segregation	/ 8.79	4.55	4.91	3.93	3.31	.....	.....
H31	Carbon O	.646	.643	.647	.655	.658	.650	.....
	Carbon M	.717	.679	.657	.646	.668	.665	.....
	Segregation	/ 10.99	5.60	1.55	−1.37	1.52	2.31	.....
H33	Carbon O	.776	.675	.679	.672	.678	.....	.....
	Carbon M	.800	.729	.702	.706	.710	.....	.....
	Segregation	18.34	/ 8.00	3.39	5.06	4.72	.....	.....
H34	Carbon O	.659	.655	.661	.665	.656	.....	.....
	Carbon M	.823	.725	.724	.723	.707	.....	.....
	Segregation	24.89	/ 10.69	9.53	8.72	7.77	.....	.....
H35	Carbon O	.622	.633	.639	.639	.625	.633	.....
	Carbon M	.842	.684	.677	.663	.646	.647	.....
	Segregation	35.37	/ 8.06	5.95	3.76	3.36	2.21	.....
H36	Carbon O	.634	.642	.654	.640	.648	.637	.....
	Carbon M	.796	.722	.655	.666	.649	.655	.....
	Segregation	25.55	12.46	/ .15	4.06	.15	2.83	.....

TABLE 20.—Percentage Segregation of Carbon in the "A" and Discard Rails of Comparison Ingots[a]



Ingot	Carbon	L	M	N	O	P	Q	R	S	T	U	V	W
M1	Carbon O	0.488	0.564	0.554	0.573	0.579	0.588	0.616	0.637	0.629	0.638	0.631	0.629
	Carbon M	.619	.630	.731	.848	.808	.791	.750	.740	.707	.683	.717	.662
	Segregation	26.84	11.70	31.95	47.99	39.55	34.52	21.75	16.17	12.40	7.05	13.63	/ 5.25
M2	Carbon O	.511	.558	.602	.622	.630	.644	.619	.641	.....	.....	.....	.....
	Carbon M	.886	1.086	.915	.898	.894	.878	.849	.811	.....	.....	.....	.....
	Segregation	73.39	94.62	51.99	44.37	41.90	36.34	37.16	26.52	/.....	.....	.....	.....
M3	Carbon O	.600	.625	.635	.665	.663	.616	.667	.676	.673	.....	.....	.....
	Carbon M	.774	.988	.889	.847	.810	.818	.792	.756	.708	.....	.....	.....
	Segregation	29.00	58.08	40.00	27.37	22.17	32.79	18.74	/ 11.83	5.20	.....	.....	.....
M4	Carbon O	.496	.630	.555	.626	.643	.664	.671	.659	.647	.....	.....	.....
	Carbon M	.661	.704	.884	.900	.861	.808	.752	.669	.690	.....	.....	.....
	Segregation	33.27	11.75	59.28	43.77	33.90	21.69	12.07	/ 1.52	6.65	.....	.....	.....
M5	Carbon O	.589	.605	.621	.626	.652	.630	.647	.652	.658	.641	.....	.....
	Carbon M	.672	.777	.927	.919	.844	.786	.761	.700	.734	.721	.....	.....
	Segregation	14.09	28.43	49.28	46.81	29.45	24.76	17.62	7.36	11.55	12.48	/.....	.....
M6	Carbon O	.618	.648	.662	.666	.677	.674	.684	.683	.690	.684	.687	.....
	Carbon M	.685	.701	.754	.783	.807	.769	.766	.769	.727	.764	.727	.....
	Segregation	10.84	8.18	13.90	17.57	19.20	14.09	11.99	12.59	/ 5.36	11.70	5.82	.....
M7	Carbon O	.640	.651	.662	.654	.666	.679	.678	.685	.689	.686	.677	.....
	Carbon M	.670	.718	.769	.799	.788	.777	.764	.729	.719	.714	.704	.....
	Segregation	4.69	10.29	16.16	22.17	18.32	14.43	12.68	/ 6.42	4.35	4.08	3.99	.....
M8	Carbon O	.585	.666	.655	.657	.662	.667	.667	.697	.691	.691	.687	.....
	Carbon M	.690	.667	.793	.805	.838	.797	.757	.732	.754	.727	.699	.....
	Segregation	17.95	0.15	21.07	22.53	26.59	19.49	13.49	/ 5.02	9.12	5.21	1.75	.....
M9	Carbon O	.626	.654	.671	.656	.700	.688	.699	.705	.706	.706	.703	.....
	Carbon M	.545	.685	.746	.839	.841	.818	.800	.786	.764	.743	.735	.....
	Segregation	−12.94	4.74	11.18	27.90	20.14	18.90	14.45	/ 11.49	8.22	5.24	4.55	.....

[a] The rails were broken at about 5-foot intervals for analysis in accordance with diagram to determine the top discard necessary to eliminate carbon segregation above 12 per cent. The point at which the segregation becomes less than this amount is indicated by "/" in the table.

TABLE 20.—Percentage Segregation of Carbon in the "A" and Discard Rails of Comparison Ingots—Continued

Ingots	Carbon	L	M	N	O	P	Q	R	S	T	U	V	W
M11	Carbon O	0.703	0.723	0.724	0.712	0.701	0.717	0.705	0.688	0.693	0.689	.....	.....
	Carbon M	.770	.799	.770	.728	.758	.708	.698	.661	.669	.701	.....	.....
	Segregation	/ 9.53	10.51	6.35	2.25	8.13	− 1.26	−0.99	−3.92	−3.46	1.74	.....	.....
M12	Carbon O	.620	.671	.670	.701	.710	.699	.698	.692	.696	.680	.....	.....
	Carbon M	.816	.830	.871	.887	.806	.778	.745	.713	.672	.686	.....	.....
	Segregation	31.61	23.70	30.00	26.53	13.52	/ 11.30	6.73	3.03	−3.45	0.88	.....	.....
M13	Carbon O	.697	.694	.711	.712	.716	.713	.720	.707	.724	.709	.....	.....
	Carbon M	.765	.776	.788	.750	.778	.765	.688	.707	.653	.640	.....	.....
	Segregation	/ 9.76	11.82	10.83	5.34	8.66	7.29	−4.44	0.00	−9.81	−9.73	.....	.....
M14	Carbon O	.714	.711	.694	.700	.692	.705	.705	.706	.708	.682	0.701	.....
	Carbon M	.684	.742	.756	.781	.783	.776	.746	.736	.705	.679	.637	.....
	Segregation	−4.20	4.36	8.93	11.57	13.15	/ 10.07	5.82	4.25	−0.42	−0.44	−9.13	.....
M15	Carbon O	.695	.690	.705	.693	.701	.692	.685	.705	.712	.716	.704	0.663
	Carbon M	.664	.816	.797	.770	.815	.780	.722	.690	.696	.671	.677	.706
	Segregation	−4.46	18.26	13.05	11.11	16.26	12.72	/ 5.40	−2.13	−2.25	−6.28	−3.84	6.49

A striking characteristic of this group (M11–M15) is the freedom from segregation in the A position; excluding M12 A for which the segregation is 32.52 per cent, the average for the others is about 2 per cent segregation at the A position (Table 16). M12 also possesses the following irregular segregation characteristics: At A there is segregation to such an extent that the steel is hypereutectoid; at B, a narrow hypereutectoid streak exists: at C there is the same structure as at A; and again at D a heavy hypoeutectoid streak.

(*c*) Segregation of Elements Other Than Carbon.—In general, it might be expected that the elements sulphur and phosphorus would follow carbon in segregation characteristics, and that manganese, silicon, chromium, and nickel would show little or no segregation. These expectations are borne out in both the sink-head and comparison ingots.

Longitudinal segregation of phosphorus is absent for the O position and slight for the M position. There is practically no longitudinal or transverse sulphur segregation in the sink-head ingots, while for the comparison ingots the results on sulphur segregation were erratic but on the whole follow that of the carbon. For the elements manganese, nickel, chromium, and silicon there is no well-defined segregation within the ingot.

7. MECHANICAL TESTS

The mechanical tests included the ordinary drop test made on the first 5-foot piece below the top of the ingot showing physically sound steel. For the Hadfield rails this location was, in all but two cases, determined by the junction of sink head with the ingot proper. The 5-foot pieces formed by cutting up the A rails (also the X rail from the comparison ingots), as well as the test pieces, B, C, D, E (and F for the comparison ingots), were examined for hardness (Brinell and scleroscope) and behavior when stressed in tension.

(*a*) Method of Expressing the Results of Mechanical Tests.—It was thought best to express measurements, such as yield point, ultimate tensile strength, elongation, etc., in terms of the average and average deviation from the mean.[5]

When using the usual method of expressing results of this kind in terms of maximum and minimum values, undue emphasis is placed upon the occasional widely divergent figure, while the very

[5] The deviation of a single observation is the amount by which that observation departs from the mean or average value. By subtracting each observation from the mean without regard to sign, and averaging these, the average deviation from the mean is obtained.

close agreement that may exist is not brought to light. Graphic plots of the various physical properties of both kinds of steel will be found in Figs. 13 to 17, inclusive.

TABLE 21.—Total Top Discard Required in Sink-Head Ingots[a]

Ingot	Weight of ingot	Bloom crop	Rail crop	Number of 5-foot pieces of rail	Length of cut	Amount of rail to cut	Rail discard, per cent of ingot	Bloom crop and rail discard	Total top discard required, per cent of ingot
	Pounds	Pounds	Feet		Feet	Pounds		Pounds	
H1	5300	190	5	3	20	667	12.6	857	16.2
H2	5300	155	5	2	15	500	9.4	655	12.3
H3	5300	205	11	1	16	533	10.1	738	13.9
H4	5350	270	5	3	20	667	12.5	937	17.5
H6	5300	324	5	1	10	333	6.3	657	12.4
H7	5250	234	5	2	15	500	9.5	734	14.0
H8	5300	142	10	1	15	500	9.4	642	12.1
H9	5300	294	5	2	15	500	9.4	794	15.0
H10	5250	320	5	2	15	500	9.5	820	15.6
H11	5300	325	8	1	13	433	8.2	758	14.3
H12	5350	204	10	0	10	333	6.2	537	10.0
H13	5300	191	5	2	15	500	9.4	691	13.0
H14	5300	231	5	2	15	500	9.4	731	13.8
H15	5300	167	5	2	15	500	9.4	667	12.6
H16	5350	199	9	1	14	467	8.7	666	12.4
H17	5300	145	10	0	10	333	6.3	478	9.0
H18	5300	237	5	2	15	500	9.4	737	13.9
H19	5300	160	9	1	14	467	8.8	627	11.8
H20	5300	276	9	1	14	467	8.8	743	14.0
H21	5300	442	5	1	10	333	6.3	775	14.6
H22	5250	437	5	0	5	167	3.2	604	11.5
H23	5350	134	8	1	13	433	8.1	567	10.6
H24	5300	185	9	2	19	633	11.9	818	15.4
H25	5300	160	10	0	10	333	6.3	493	9.3
H26	5300	160	8	2	18	600	11.3	760	14.3
H27	5300	245	8	0	8	267	5.0	512	9.7
H28	5300	233	5	2	15	500	9.4	733	13.8
H29	5350	566	5	1	10	333	6.2	899	16.8
H30	5300	247	8	0	8	267	5.0	514	9.7
H31	5300	234	7	0	7	233	4.4	467	8.8
H33	5300	228	8	1	13	433	8.2	661	12.5
H34	5300	195	12	1	17	567	10.7	762	14.4
H35	5300	280	5	1	10	333	6.3	613	11.6
H36	5300	342	5	2	15	500	9.4	842	15.9

[a] The above discard includes amount necessary to eliminate piping and segregation above 12 per cent

TABLE 22.—Total Top Discard Required in Comparison Ingots[a]

Ingot	Weight of ingot	Bloom crop	Rail crop	Number of 5-foot pieces of rail	Length of cut	Amount of rail to cut	Rail discard, per cent of ingot	Bloom crop and rail discard	Total top discard required, per cent of ingot
	Pounds	Pounds	Feet		Feet	Pounds		Pounds	
M1	7360	183	5	12	65	2167	29.4	2350	31.9
M2	7030	243	5	8	45	1500	21.3	1743	24.8
M3	7040	185	5	8	45	1500	21.3	1685	23.9
M4	7130	189	5	8	45	1500	21.0	1689	23.7
M5	7190	223	5	10	55	1833	25.5	2056	28.6
M6	7340	189	5	9	50	1667	22.7	1856	25.3
M7	7200	205	5	8	45	1500	20.8	1705	23.7
M8	7260	188	5	8	45	1500	20.7	1688	23.3
M9	7240	225	5	8	45	1500	20.7	1725	23.8
M11	7540	664	5	0	5	167	2.2	831	11.1
M12	7340	288	5	6	35	1167	15.9	1455	19.8
M13	7190	490	5	0	5	167	2.3	657	9.1
M14	7320	379	5	6	35	1167	15.9	1546	21.1
M15	7480	236	5	7	40	1333	17.8	1569	21.0

[a] The above discard includes amount necessary to eliminate piping and segregation above 12 per cent.

(*b*) Ultimate Strength and Yield Point.—The ultimate strength of the steel in rails from both types of ingots are of the same order of magnitude, about 125 000 pounds per square inch.

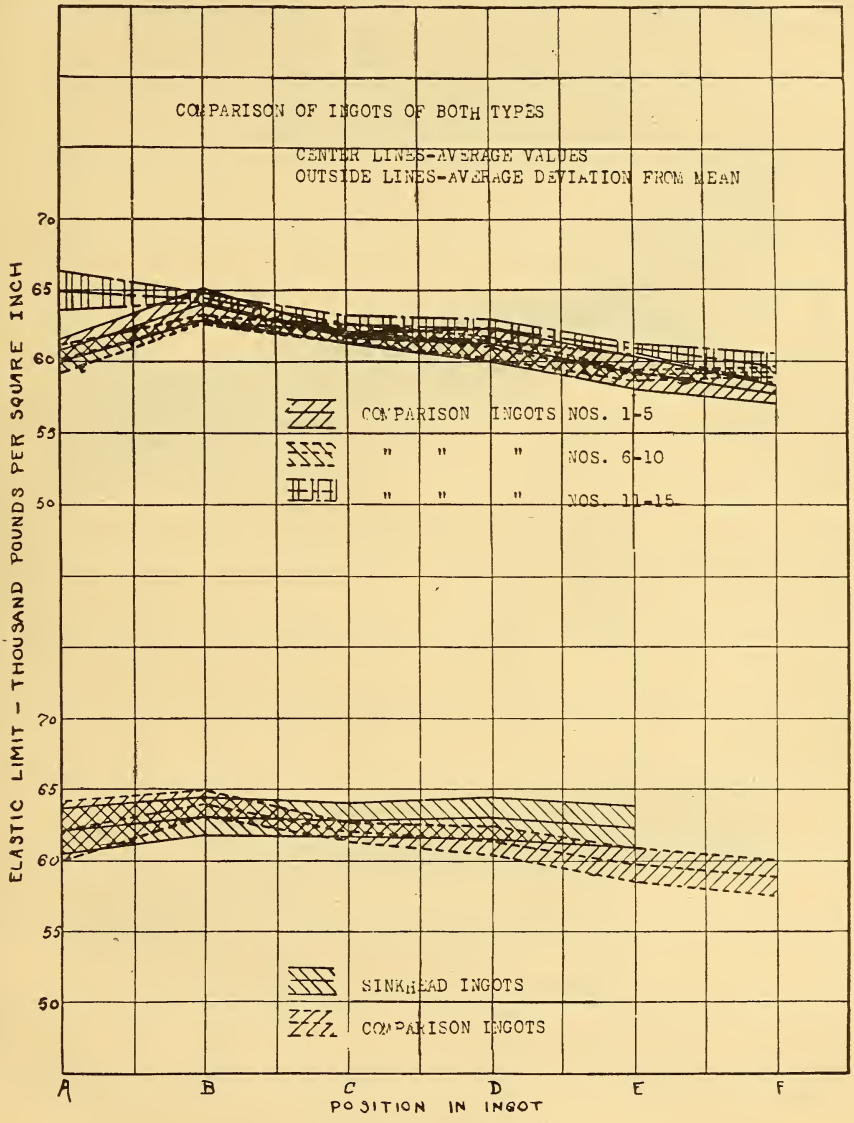


Fig. 13.—*Elastic limit of ingots of both types*

For the 35 sink-head ingots the nonuniformity, expressed as the average deviation from the mean for values at the A, B, C, D, and E positions, is somewhat greater than for the comparison ingots, except for the A position, at which the results are erratic (Tables 13 and 14).

If we consider the ultimate strength throughout the length of the ingot, we note for the sink-head ingots there is practical uniformity down to the E position; for the comparison ingots, on the

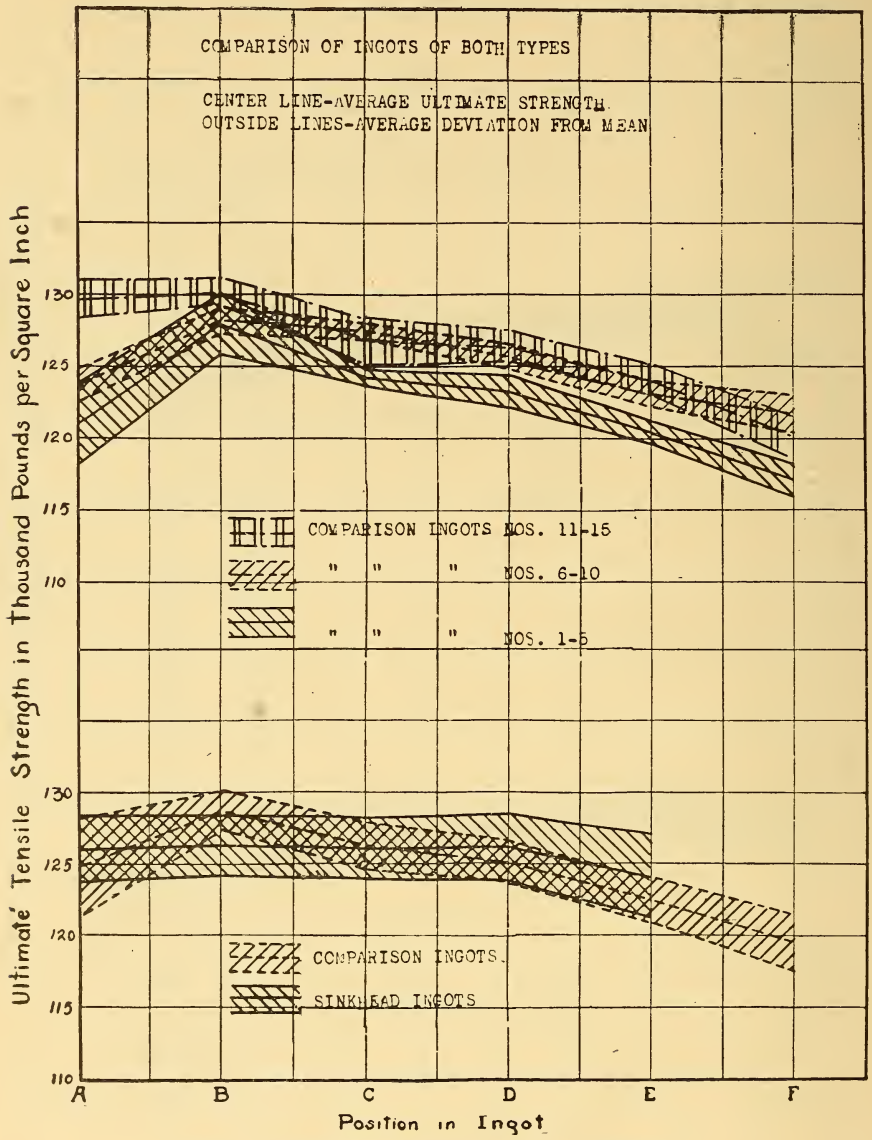


FIG. 14.—*Ultimate strength of ingots of both types*

other hand, there is an abrupt increase in ultimate strength from the A to the B position and a gradual falling off until the bottom of the ingot is reached, so that at the F position the ultimate tensile strength is some 9000 pounds per square inch less than the maximum at B.

If the comparison ingots are considered by groups corresponding to heats, it is seen that the ultimate strength of each group may be distinguished from the others. Thus groups M1–M5 and M6–M10

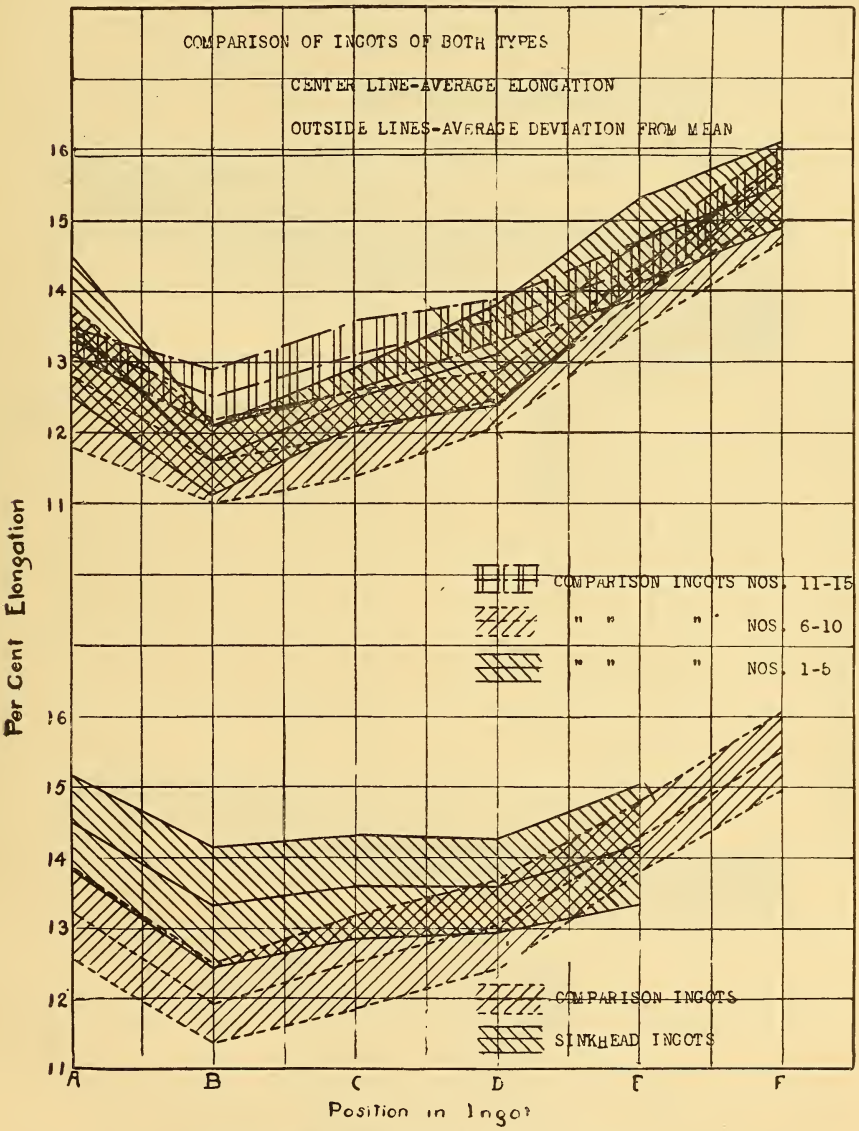


FIG. 15.—*Elongation of ingots of both types*

run closely parallel through the ingot, with M6–M10 having slightly higher ultimate strength. Group M11–M15 is characterized by the abnormally high value (approximately 130 000 pounds per square inch) in the A and B positions.

The yield point shows, in general, characteristics similar to the ultimate strength; for the former, however, there is a somewhat greater uniformity throughout the ingot for all types, and also for

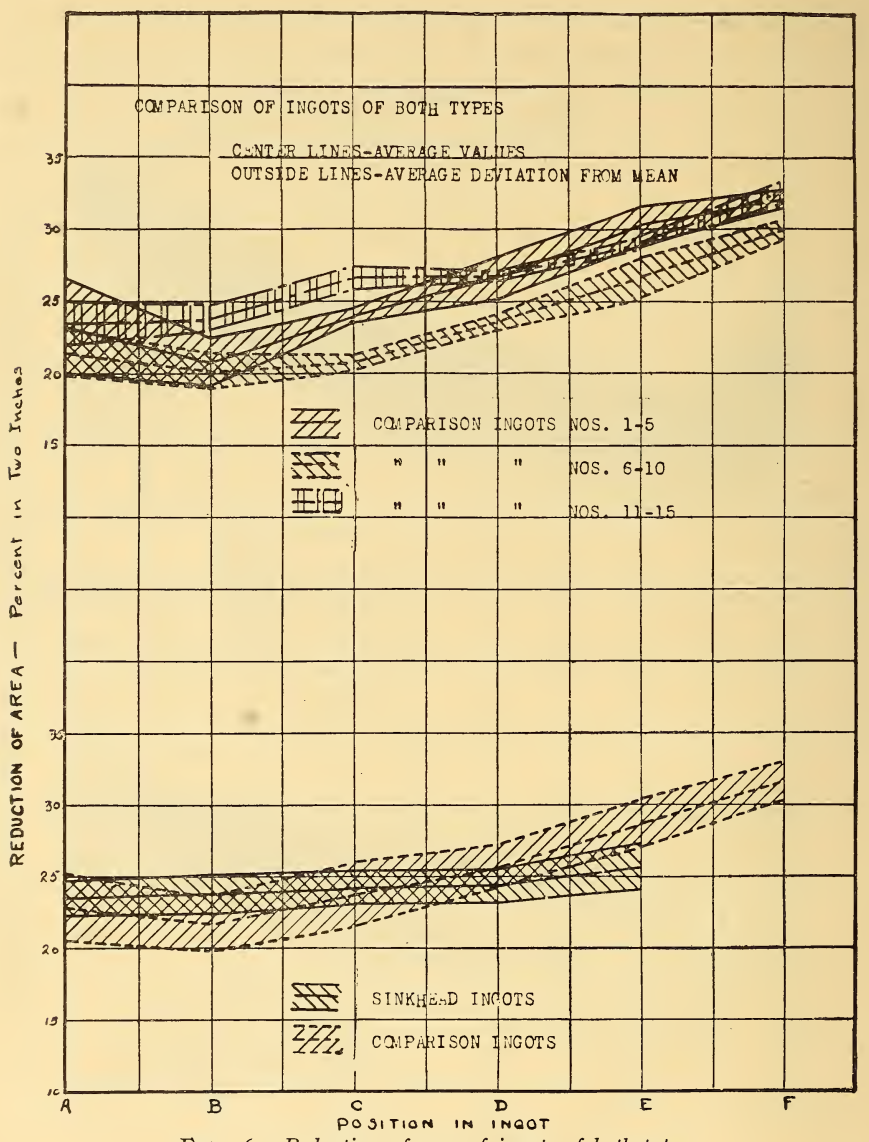


FIG. 16.—*Reduction of area of ingots of both types*

the ingots of a given group. The sink-head ingots have a slightly higher yield point (62 370 pounds per square inch) than the comparison ingots (61 370 pounds per square inch). For the three groups of the latter there is a falling off throughout the length of the ingot from approximately 64 000 pounds to 59 000 pounds per

square inch (as for the ultimate strength), while for the sink-head ingots the yield point remains practically constant throughout.

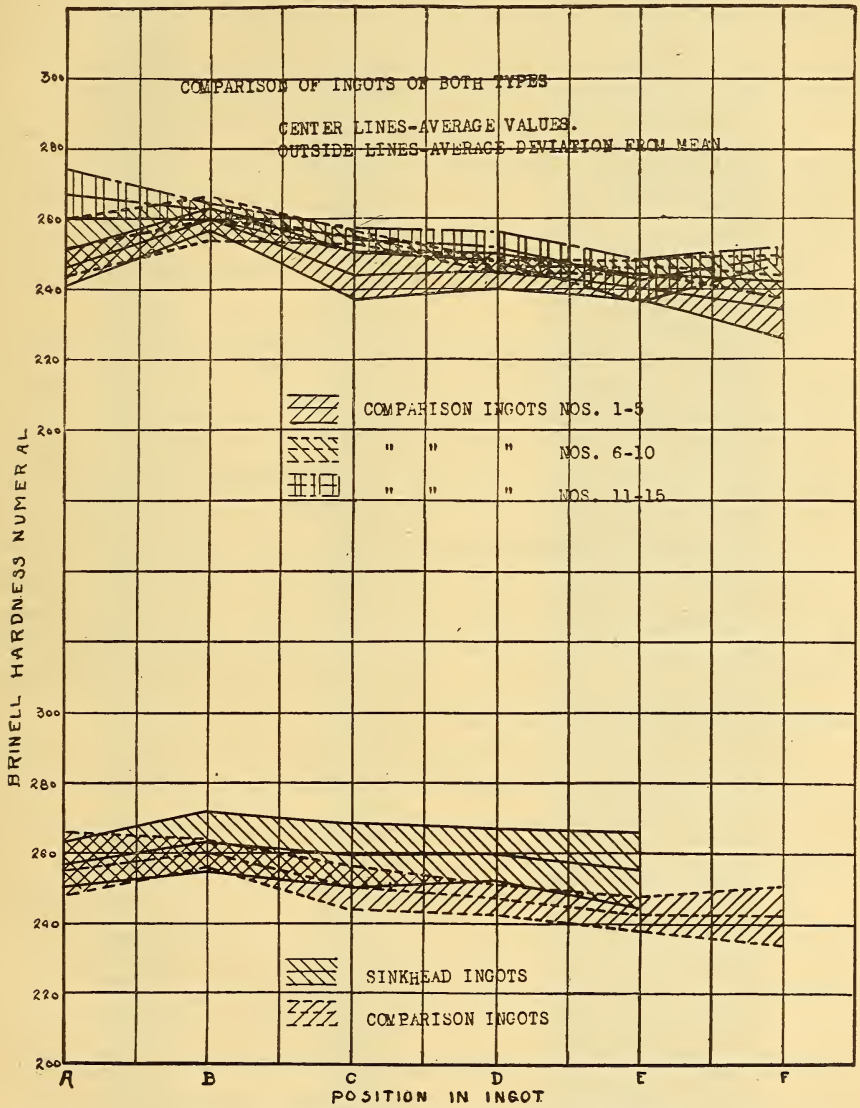


FIG. 17.—*Brinell hardness of ingots of both types*

(*c*) ELONGATION AND REDUCTION OF AREA.—The distribution of ductility, as measured by elongation in tension-test pieces from rails through the length of the sink-head ingots, is somewhat more uniform than for the comparison ingots. The elongation curves are practically the reciprocal of the tensile-strength curves.

The average elongation of the rails from the sink-head ingots is 13.8 per cent, of the comparison ingots 13.6 per cent; the reduction of area for the former type of ingot is 24.38 per cent, for the latter type it is 25.78 per cent, with a range of 21.73 per cent at B to 31.68 per cent at the F position. There are also considerable differences among the three groups of comparison ingots.

(*d*) HARDNESS.—The scleroscope hardness numbers do not appear to have any significance in defining any differences in qualities or properties in the steel of the several ingots. The material from the sink-head ingots have an average hardness of 31, while the steel from ingots cast in the usual manner has an average hardness of 32.

The Brinell numerals are, as would be expected, fairly closely proportional to the ultimate strengths, and they appear to follow even more exactly the yield points. Whether or no there is any definite relation between carbon segregation and Brinell numerals appears difficult to say. The holes for obtaining drillings for the former are ½ inch in diameter and not always exactly coincident in location with the Brinell impression. In a general way one would expect the two to bear some relation to each other. The rails from the sink-head ingots had an average Brinell hardness of 260 (deviation ±8), while the rails made from ingots cast with the small end uppermost without sink heads had a Brinell hardness of 250 (deviation ±6).

(*e*) DROP TESTS.—In the drop tests blows were given on head of rail to destruction, the deflection was measured for each blow, the elongation for each inch over 6 inches and the total elongation noted.

The drop-test piece was taken from near the top of the ingot, and in each case was the first 5-foot length of rail immediately after reaching physically sound steel; that is, free from pipe and in the case of the rails from sink-head ingots also below the bottom of the sink head. Of the 14 comparison rails none broke under 4 or 5 blows (6 rails were nicked and broken after the fourth or fifth blow), while for the 35 Hadfield rails the range was 2 to 7 blows, there being 9 requiring 4 blows, and 4 requiring 3 blows; only 22, or 63 per cent, of the rails from sink-head ingots withstood 4 or more blows. The ductility as measured by the deflection and elongation is also somewhat greater and more uniform for the comparison rails.

The greater uniformity of the sink-head over the comparison ingots, as shown in nearly all other mechanical tests,

FIG. 5.—*Photograph of sulphur print of top bloom from comparison ingot No. 10*

FIG. 6.—*Photograph of sulphur print of top bloom from sink-head ingot No. 5*

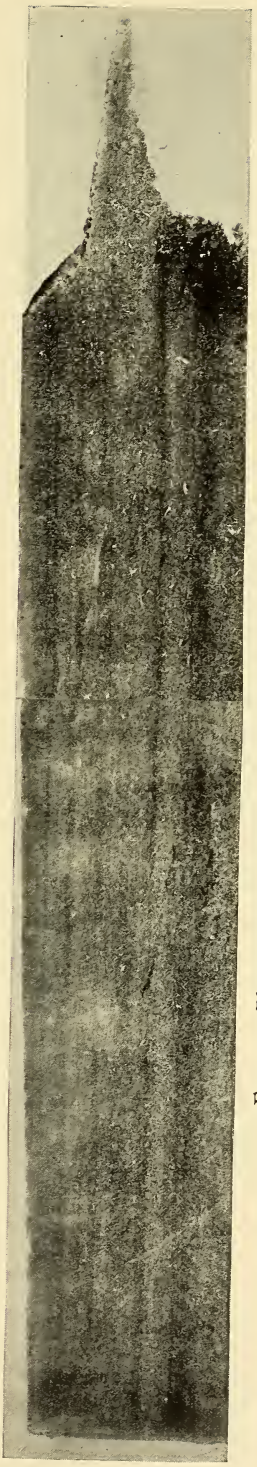


FIG. 7.—*Photograph of sulphur print of half section of sink-head ingot No. 32*

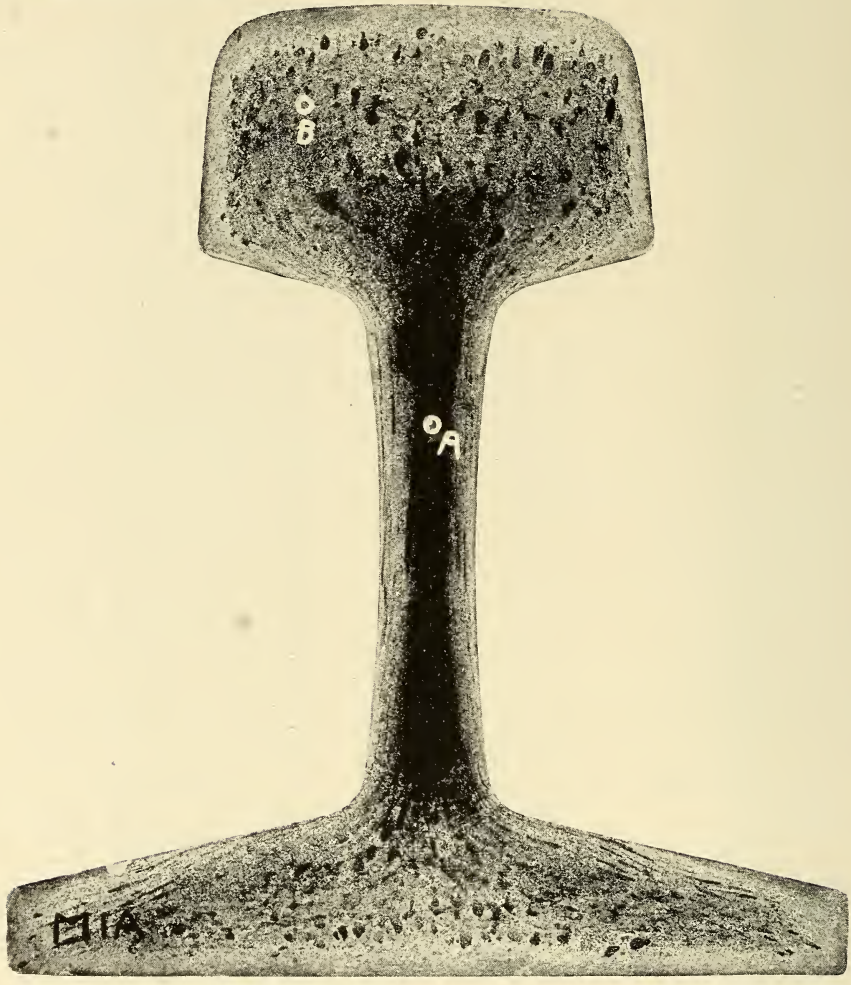
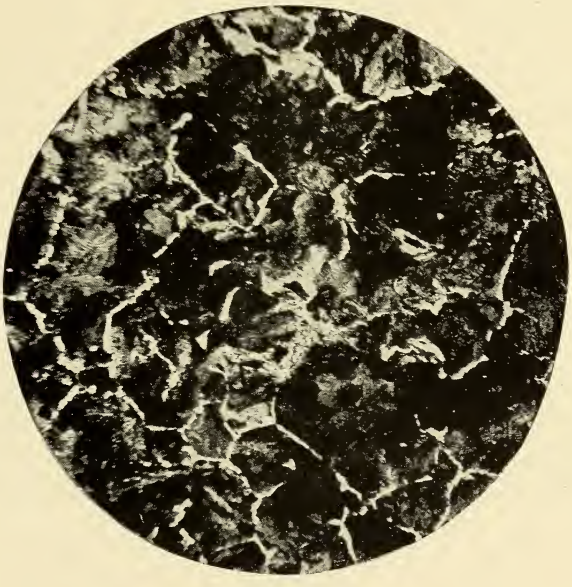


FIG. 8.—*Rail M1–A from comparison ingot*

Sulphur print, showing extreme segregation in rail from top of ingot. × 1

a



b

FIG. 8.—*Rail M1–A from comparison ingot (continued)*

Typical microstructure of the metal of rail M1–A at positions indicated in sulphur print. × 50, reduced from × 100

(*a*) Moderately finely grained hypereutectoid steel, pearlite with a trace of free cementite and many small slag inclusions

(*b*) Moderately finely grained hypoeutectoid steel, pearlite with a thick irregular ferrite network

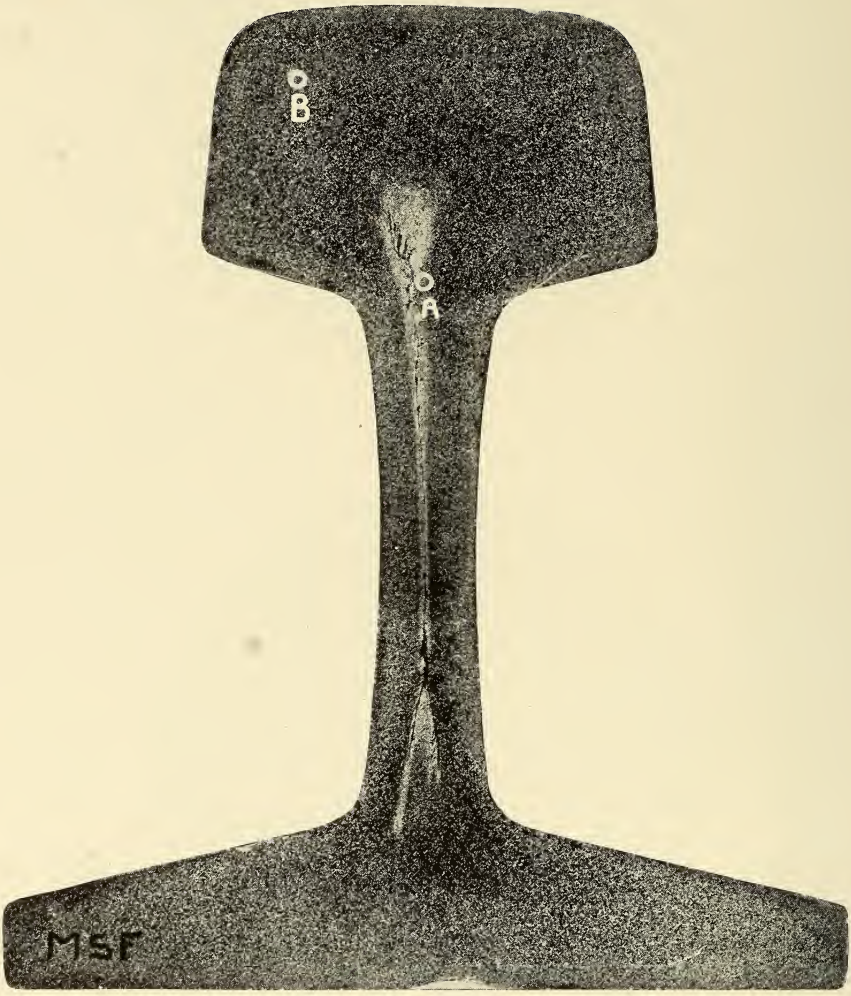
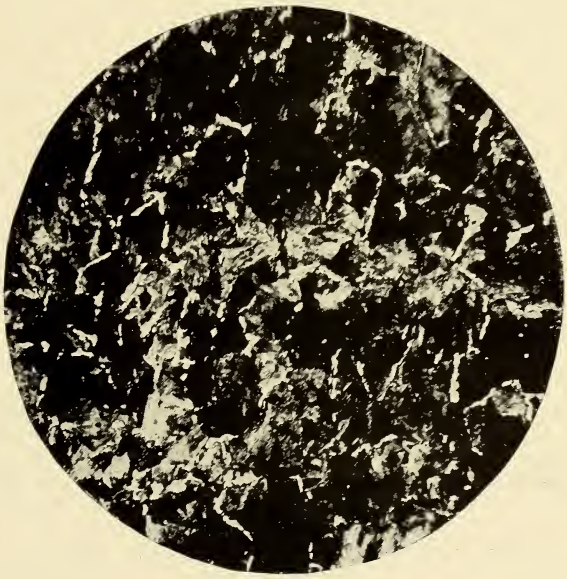


FIG. 9.—*Rail M5–F from comparison ingot*

Sulphur print, showing pipe in rail from bottom portion of ingot (F position). × 1

a



b

FIG. 9.—*Rail M5–F from comparison ingot (continued)*

Typical microstructure of the metal of rail M5–F at positions indicated in the sulphur print. × 50, reduced from × 100

(*a*) Structure at the edge of a pronounced pipe, consisting of eutectoid steel contaminated with slag and bordered by a layer of hypoeutectoid metal

(*b*) Moderately finely grained metal, consisting of pearlite with a trace of ferrite, and containing some slag intrusions

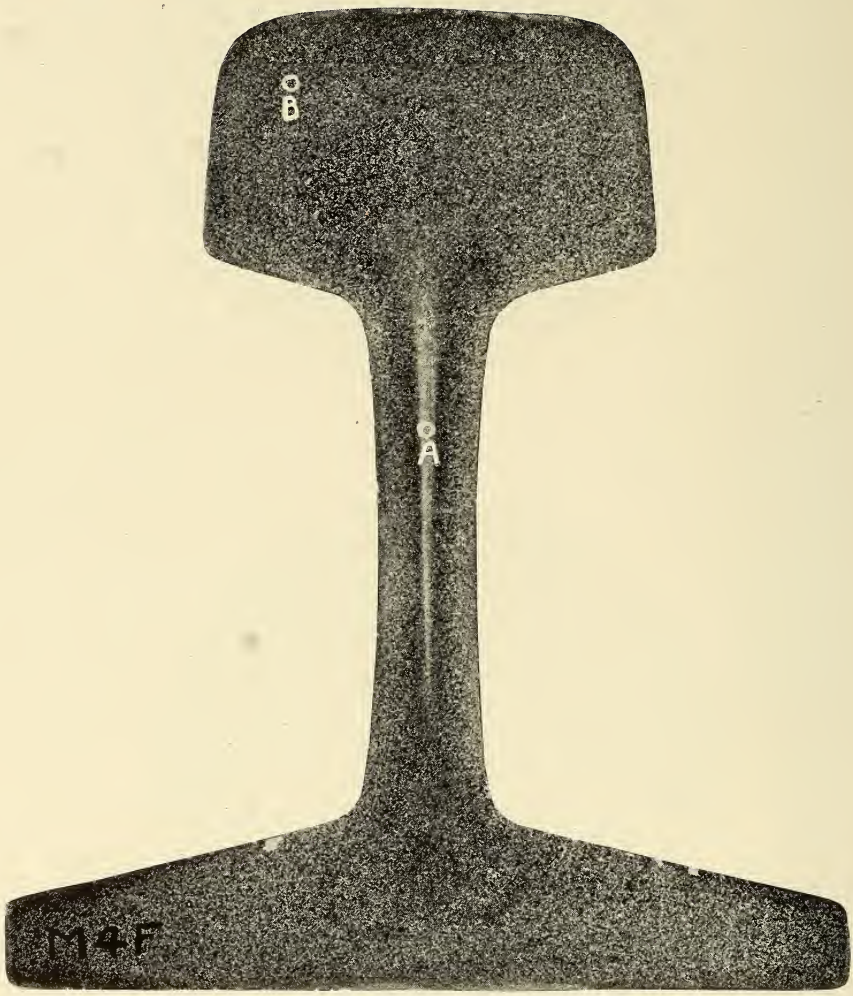
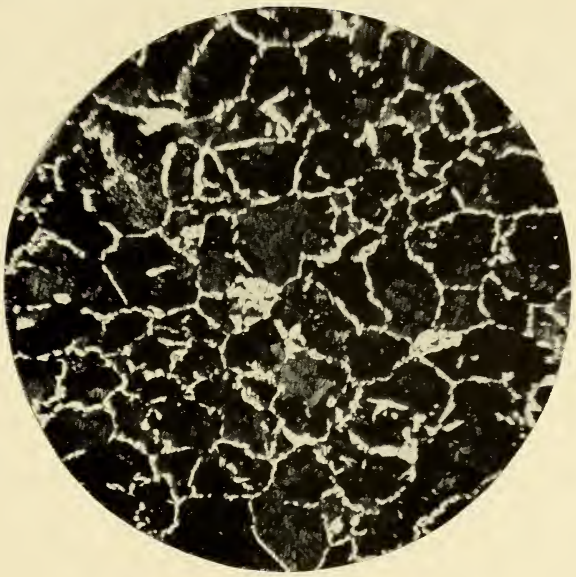
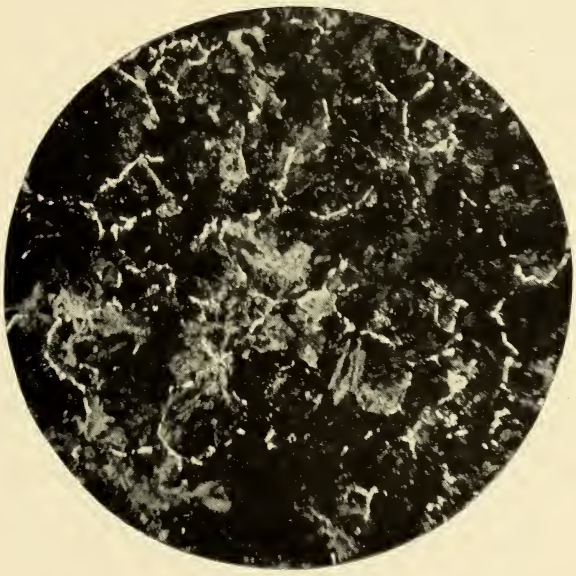


FIG. 10.—*Rail M4–F from comparison ingot*

Sulphur print, showing soft streak in web at F position (bottom of ingot). × 1



a



b

FIG. 10.—*Rail M4–F from comparison ingot (continued)*

Typical microstructure of the metal of rail M4–F at the positions indicated in the sulphur print. × 50, reduced from × 100

(*a*) Streak of soft metal in the web, consisting of pearlite crystals surrounded by well developed ferrite envelopes

(*b*) Moderately finely grained metal consisting of pearlite and a trace of ferrite

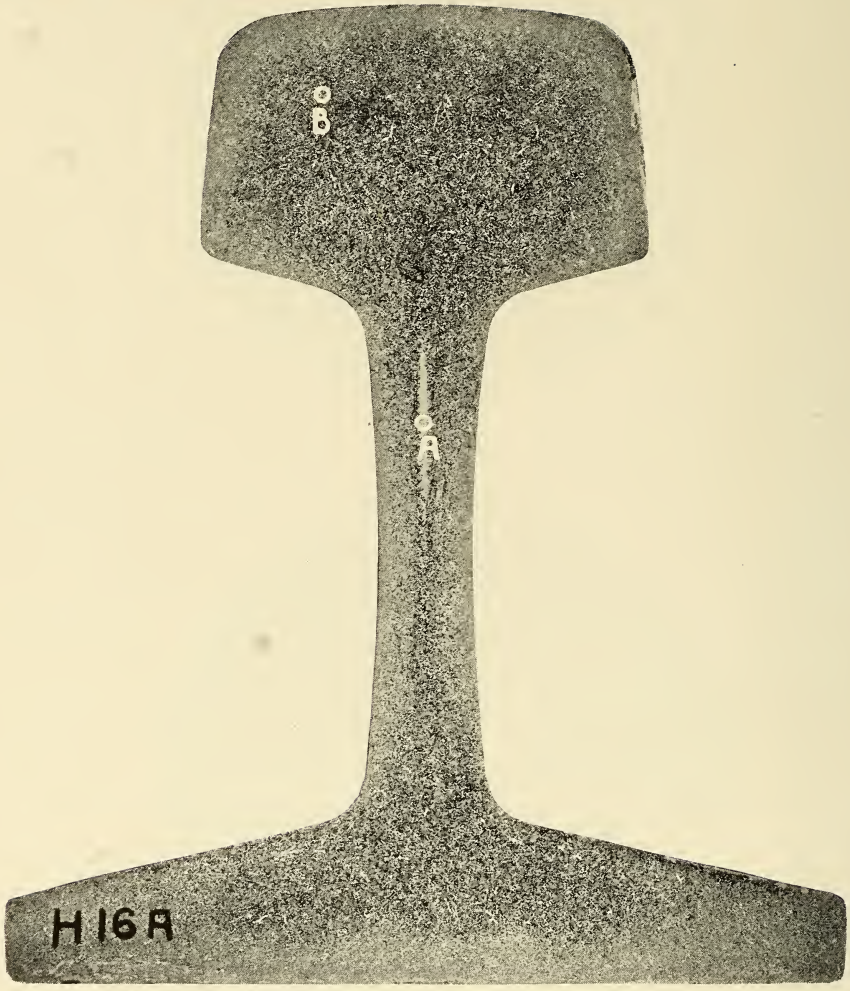


FIG. 11.—*Rail H16–A from sink-head ingot*

Sulphur print, showing slight segregation in upper part of ingot (A position). × 1

a

b

FIG. 11.—*Rail H16–A from sink-head ingot (continued)*

Typical microstructure of the metal of rail H16-A at positions indicated in the sulphur print. × 50, reduced from × 100
(*a*) Eutectoid metal comprising a slightly segregated streak in the web of the rail
(*b*) Average finely grained structure, pearlite with a trace of ferrite

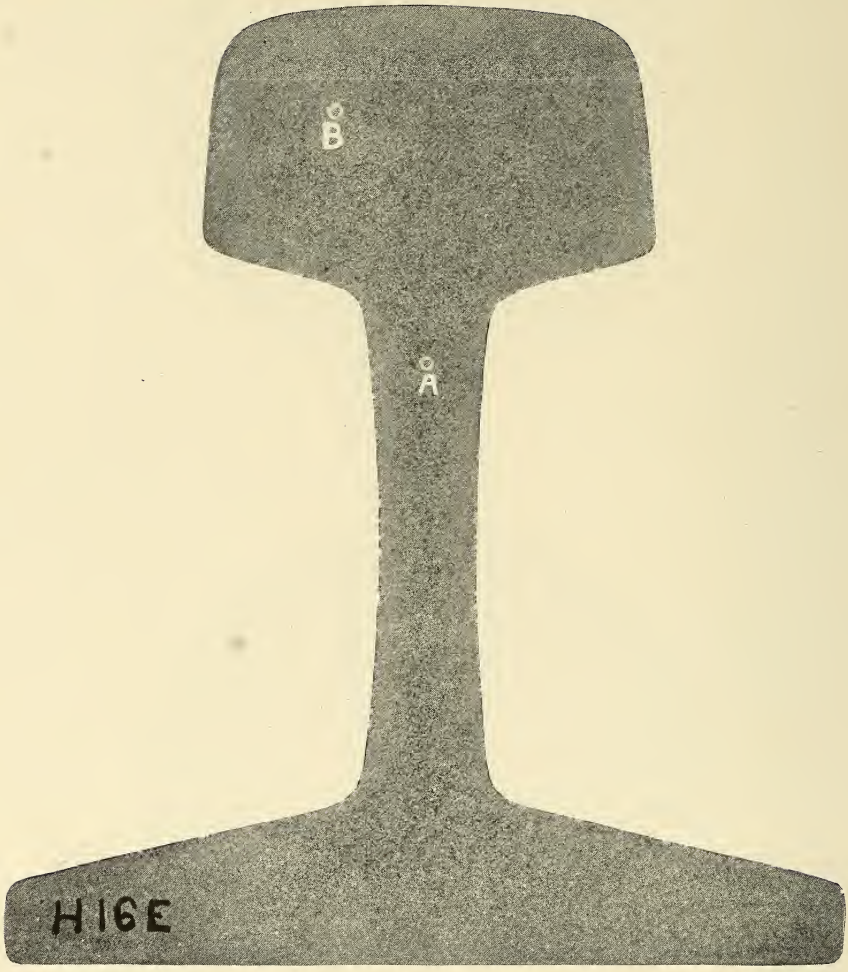
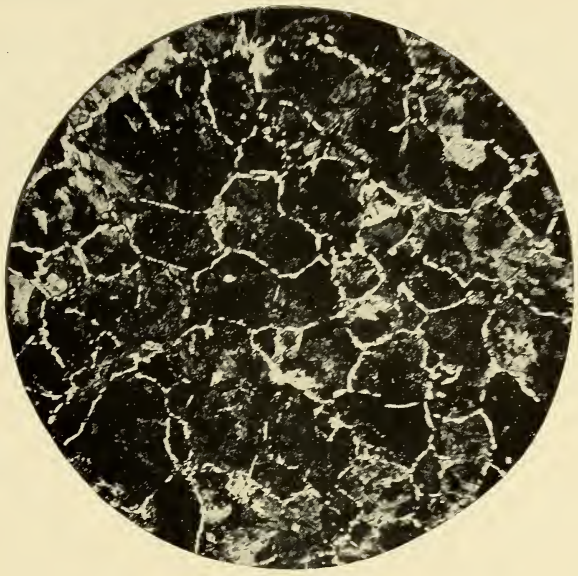
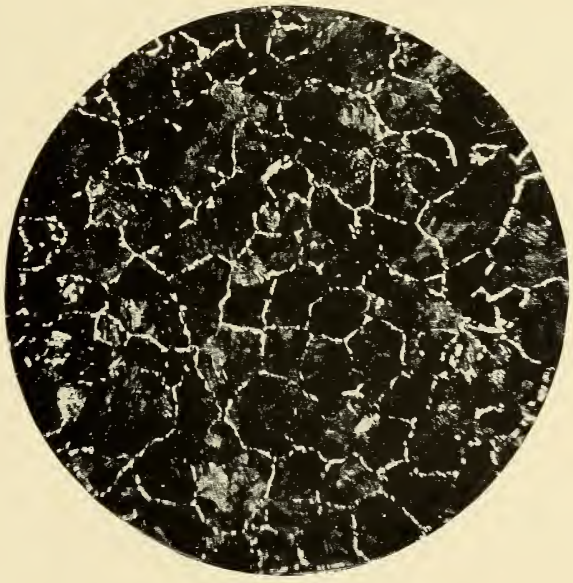


FIG. 12.—*Rail H16–E from sink-head ingot*

Sulphur print, showing sound steel in rail from bottom of ingot (E position). × 1. The rail is homogeneous



a



b

FIG. 12.—*Rail H16–E from sink-head ingot (continued)*

Typical microstructure of the metal of rail H16–E at the positions indicated in the sulphur print. × 50, reduced from × 100
(*a*) Moderately finely grained metal showing a thick ferrite network
(*b*) Finely grained metal, pearlite with a ferrite network

in less segregation, greater homogeneity as shown by sulphur prints and etching, less amount and variability in discard to sound steel, suggests that the question of the significance and interpretation of the drop test may well be raised with propriety. The greater ductility and more uniform behavior under the drop test of the steel from the comparison ingots would appear to be due more to the chemical composition, and especially to the nickel and chromium content of this Mayari steel, than to any factor traceable to manufacture, which in the case of the comparison ingots is seen to divide them sharply into three groups of very distinct physical characteristics—each a heat—which fact, the drop test is unable to reveal.

8. METALLOGRAPHIC TESTS

The metallographic tests throw additional light on the question of segregation and soundness, and especially with reference to the presence of slag inclusions, streaks, and seams. They also furnish evidence as to the uniformity of the operations in the rolling mill, although there appears also to be a distribution of structure for each ingot characteristic of its manufacturing processes preceding the rolling.

The smoothness and evenness of tone of the sulphur prints of all rail sections from the Hadfield sink-head ingots, which are characteristic of the lot (Figs. 11–12), even from sections in the drop-test portion near the top of the ingot, is in striking contrast to the markedly irregular sulphur prints from comparison rails (Fig. 8), except for a few below the center of some of these ingots. Most of the rails from the Maryland ingots show very pronounced irregularities in terms of the sulphur prints, some of them from the bottom of ingot showing well-defined pipes (Figs. 9 and 10).

As to the microstructure of the steel, here again the sink-head ingots show much the greater uniformity. This is especially true for the upper portions of the ingot, where differences would be expected.

The parallelism of segregation and type of structure is, in general, very close. Thus in the extreme top portion of the ingot there appears a fine-grained, hypereutectoid structure in the segregated area. The main differences in structure across the section, except for these extreme cases accompanying marked segregation, are usually limited to differences in grain size, pearlite with a ferrite network, the smaller-sized grain accom-

panying the higher carbon. This is the predominant characteristic of the microstructure of the rails from the sink-head ingots.

The rails from the comparison ingots have, below the segregated area, about the same structural characteristics as those from the sink-head type, except that for many of them the ferrite network is less pronounced and in some cases almost absent. The rolling and finishing temperatures of the ingots were not widely different and do not appear to play any considerable rôle in determining differences of structure. The manganese content, usually somewhat higher in the Hadfield ingots, apparently tends to accentuate the sharp, definite boundaries of ferrite surrounding the pearlite grains. A number of typical photomicrographs are shown in Figs. 8–12, inclusive.

9. EXAMINATION OF SPLIT INGOTS AND BLOOMS

(*a*) SINK-HEAD INGOT H37.—Sink-head ingot H37 was cut in halves at Sheffield and Sir Robert Hadfield reports:

> The whole of this ingot could be worked into rails after cutting off 10 per cent discard. The ingot is perfectly sound and represents the average quality of the whole of the 36 ingots sent to be rolled into rails.
>
> The capacity of the sink-head cavity of this ingot was 8125 cubic centimeters, and the percentage of settling, by weight in pounds—that is, of the total weight of the ingot—was 2.58 per cent. The weight of the material which passed from the head portion into the ingot itself was about 130 pounds. This ingot was selected because it showed the lowest cavity percentage; namely, 2.58 per cent.

(*b*) SINK-HEAD INGOT H32.—Sink-head ingot H32 was cut in halves at the Bureau of Standards. A photograph of a sulphur print of a longitudinal half section of the ingot is shown in Fig. 7. In Figs. 18–21, inclusive, are shown the location of drill holes for chemical analyses of this ingot, as well as the results of the analyses. Only carbon, phosphorus, silicon, and sulphur surveys were made, as the rail analyses indicated that there was no appreciable segregation of manganese in similar ingots. The results obtained indicate that with about 9 per cent discard, steel free from piping and appreciable segregation is obtained. Carbon showed a high degree of segregation (0.68 to 1.13 per cent), but as will be noted, this is confined to the extreme upper portion of the ingot. The high carbon content at this point is probably due to the fact that the steel in the top part of the ingot absorbed carbon from the charcoal used, together with air blast, to keep the ingot hot on its upper surface while cooling. Phosphorus, silicon, sulphur, and manganese are remarkably uniform in this sink-head type of ingot.

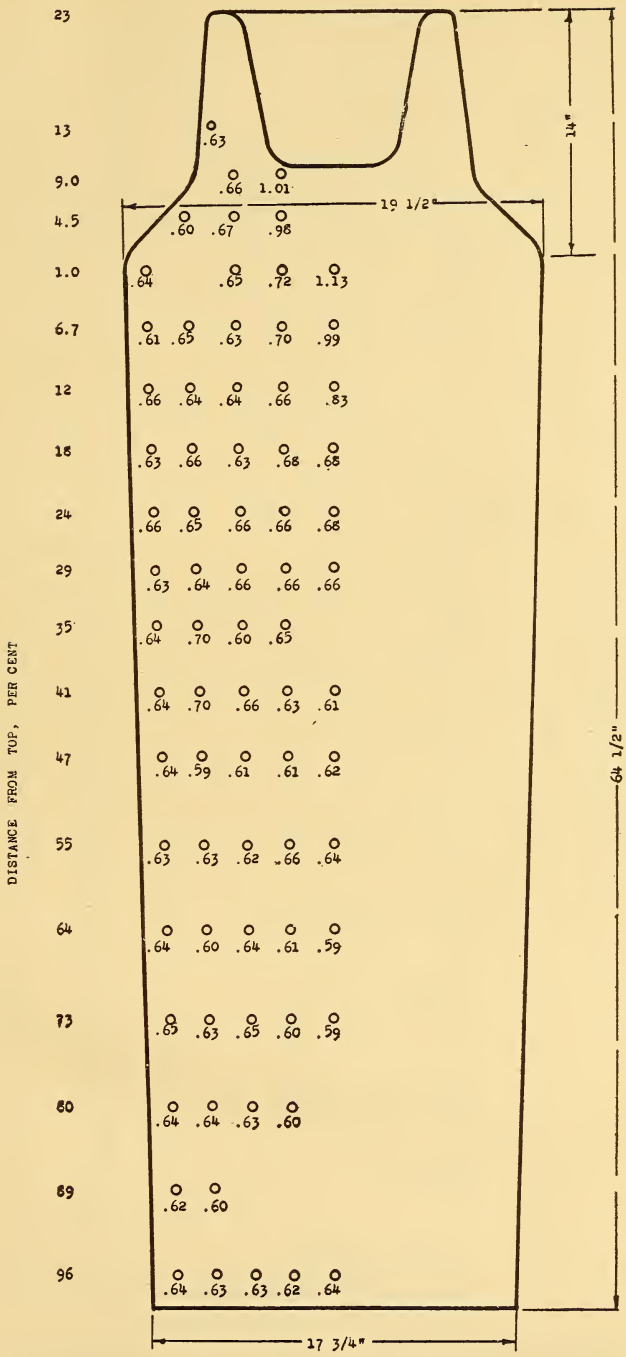


FIG. 18.—*Section of Hadfield split ingot No. 32, showing percentage of carbon*

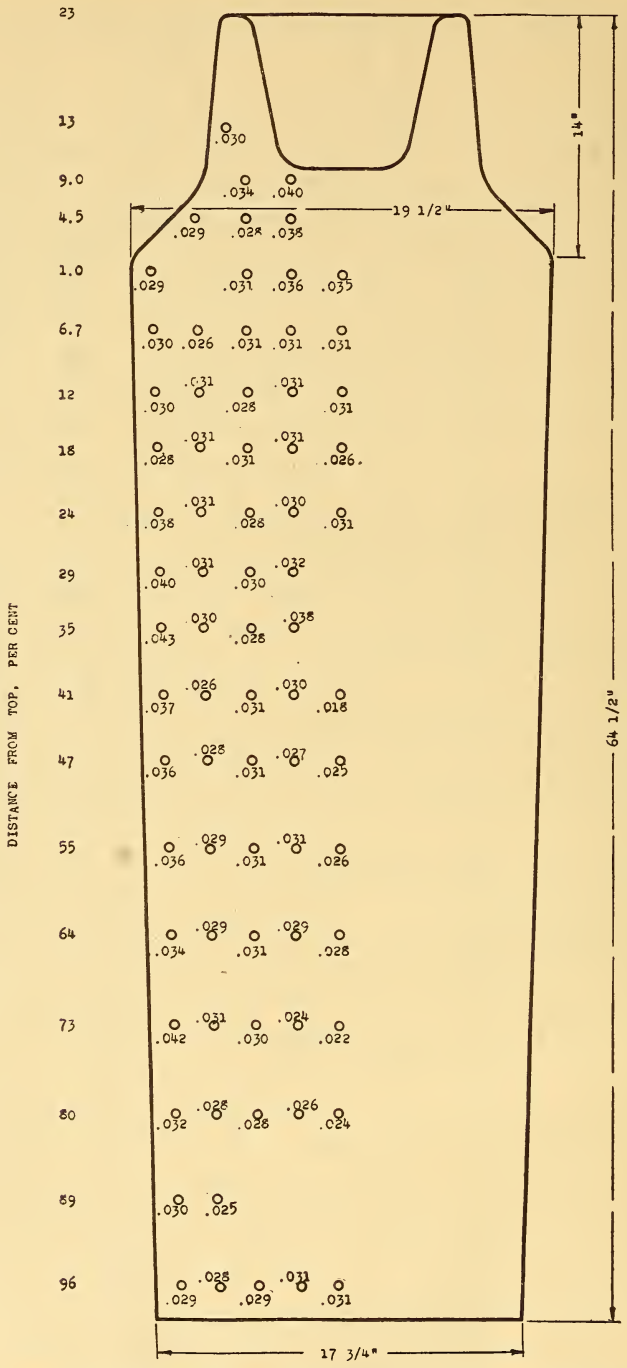


FIG. 19.—*Section of Hadfield split ingot No. 32, showing percentage of phosphorus*

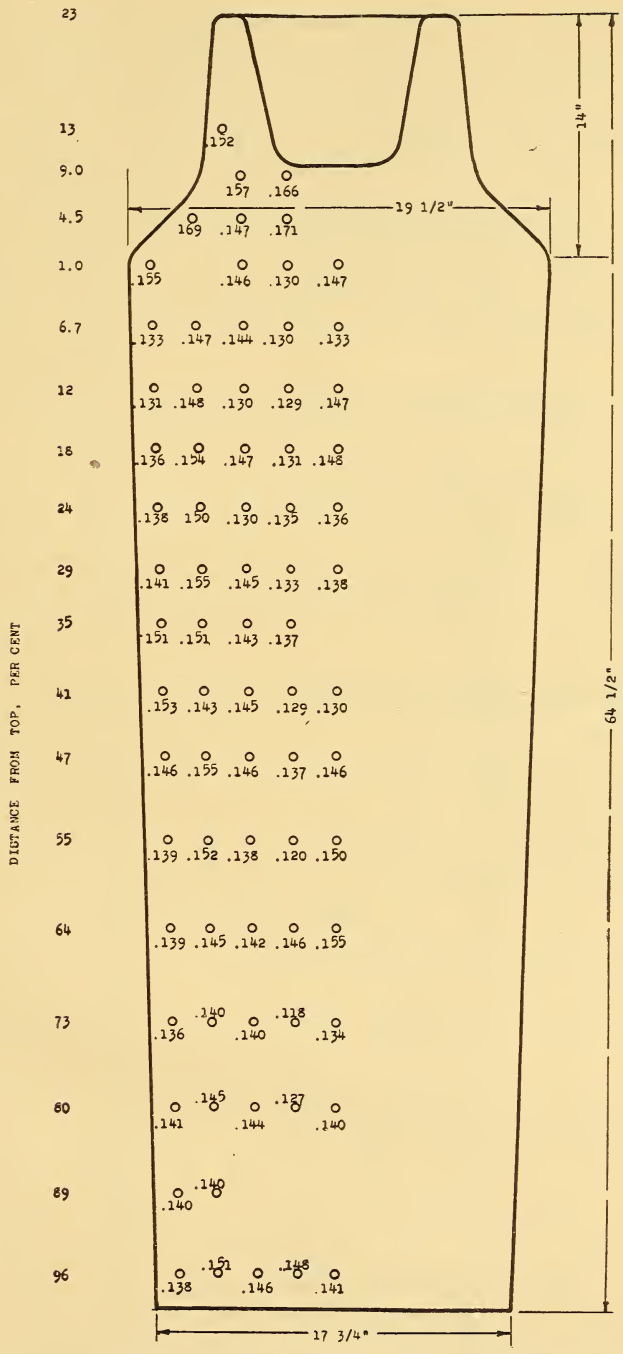


FIG. 20.—*Section of Hadfield split ingot No. 32, showing percentage of silicon*

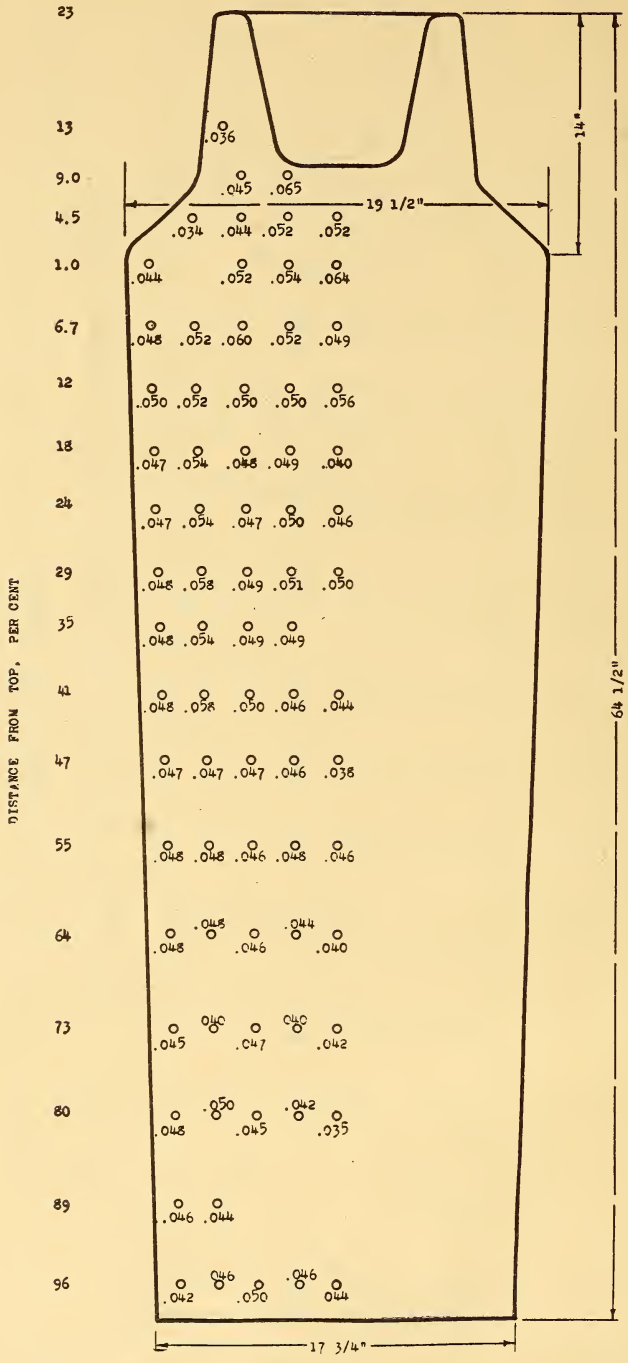


FIG. 21.—*Section of Hadfield split ingot No. 32, showing percentage of sulphur*

(*c*) Sink-Head Ingot H5 and Comparison M10 Top Blooms.—The top blooms from ingots H5 and M10 were split longitudinally at the Bureau of Standards and one half of each used for sulphur prints (Figs. 5 and 6) and the other half of each for a chemical survey (Figs. 22 and 23) of carbon, phosphorus, silicon, and sulphur segregation.

As in the case of the sulphur prints from the rails, the sulphur print from the bloom of the sink-head ingot is of even tone, while the comparison bloom shows decided irregularities (Figs. 5 and 6). In addition, the latter bloom has an inclosed pipe some 12 per cent below the top.

The chemical survey shows the Hadfield bloom to be very uniform. The maximum carbon is 0.90 per cent, and this is only 4 per cent from the top of the ingot. The comparison bloom, according to chemical analyses, is also quite uniform except for the sulphur content, which is very irregular. This element attains a maximum of 0.166 per cent at a distance of 12 per cent from the top, while it is as high as 0.12 per cent at a distance of 21 per cent.

10. SPECIAL NICKEL CHROMIUM SINK-HEAD INGOT

A special sink-head ingot, of the same dimensions and type as the other sink-head ingots but containing chromium and nickel was rolled into rails so as to permit more accurate comparison with the ingots cast in the ordinary manner. The latter naturally contain small amounts of nickel and chromium from the Mayari ore from which the product was made.

The mechanical and chemical properties of the five rails from this special ingot (H38) are given in Table 23. It will be observed that the yield point (70 791 pounds per square inch), the ultimate tensile strength (143 025 pounds per square inch), and the Brinell hardness (292) are greater, while the elongation (11.3 per cent) and reduction of area (19.06 per cent) are less than those of the average sink-head ingot. Under the drop test the rails from this ingot behave similarly to the comparison ingots.

From the standpoint of composition the steel from this ingot differs from that of the average sink-head ingot in that it is of higher carbon (0.73 per cent) and lower phosphorus (0.016 per cent) and sulphur (0.018 per cent); also in that it contains small amounts of nickel (0.19 per cent) and chromium (0.11 per cent).

It was necessary to discard 17.6 per cent of this ingot because of pipe, as against 9.1 per cent for the average sink-head ingot.

TABLE 23.—Mechanical and Chemical Properties of the Special Sink-Head (Nickel and Chromium) Ingot

Rail	Tension tests				Hardness	
	Yield point	Ultimate strength	Elongation, per cent in 2 inches	Reduction of area	Brinell	Scleroscope
	Lbs./in.²	Lbs./in.²		Per cent		
H38-A	70 030	142 725	12	18.79	274	33
H38-B	70 700	143 400	11	18.59	298	32
H38-C	70 950	143 450	12	18.54	318	29
H38-D	71 445	143 300	11.5	18.38	283	33
H38-E	70 830	142 250	10	21.00	287	31
Average	70 791	143 025	11.3	19.06	292	32

Rail	Results of chemical analysis at "O"; per cent								
	Carbon			Mn	P	Si	S	Ni	Cr
	O	M	Seg.						
H38-A	0.741	0.741	0	0.91	0.024	0.179	0.018	0.19	0.10
H38-B	.731	.729	−0.27	.95	.027	.177	.019	.19	.10
H38-C	.728	.735	.96	.93	.026	.179	.018	.19	.12
H38-D	.734	.726	−1.09	.94	.027	.185	.018	.18	.10
H38-E	.731	.730	− .14	.96	.025	.180	.019	.19	.11
Average	.733	.732	− .11	.94	.026	.180	.018	.19	.11

IV. SERVICE OF RAILS FROM THIS INVESTIGATION

The Pennsylvania Railroad, through A. W. Gibbs, reports as follows on the service of the rails from the earlier investigation [6] and from the present one:

In January, 1915, the Maryland Steel Co. shipped free for test 5 No. 1 33-foot P. S. 100-pound open-hearth steel rails rolled from ingots furnished by Sir Robert Hadfield to the Bureau of Standards. These rails were laid in the Eastward freight track on Horseshoe Curve, January 20, 1915, and removed May 15, 1915. The average abrasion of the Hadfield rails was 1.16 square inches and that of the ordinary rail 0.78 square inch. None of these rails failed.

In September, 1915, the Maryland Steel Co. rolled 46 No. 1 and 61 No. 2 P. S. 100-pound rails (0.33 track mile) from imported Hadfield sink-head ingots and at the same time rolled 53 No. 1 and 4 No. 2 P. S. 100-pound rails (0.18 track mile) from its own ingots for comparison. The 46 No. 1 Hadfield and 53 No. 1 Maryland special rails were laid November 26, 1915, in the Eastward passenger and freight track on the 5° 30′ curves between Spruce Creek and Union Furnace, Middle Division, and removed October 23, 1916. The 61 No. 2 Hadfield and 4 No. 2 Maryland special rails were laid on a 2° curve in the Eastward Low Grade track, Philadelphia Division, west of M. P. 69, and are still in track. The average abrasion of the No. 1 Hadfield rails was 0.42 square inch; that of the Maryland special rails 0.37. The rail on Low Grade was still in track October 31, 1919; abrasion was then 16.1 per cent for Hadfield and 9.7 per cent for Maryland special.

There have been no failures of Hadfield rails or of the Maryland specials.

There is evidently no economy in the Hadfield process as regards wear, and it would require a much more extended trial to determine the relative freedom from failure.

[6] See footnote 1.

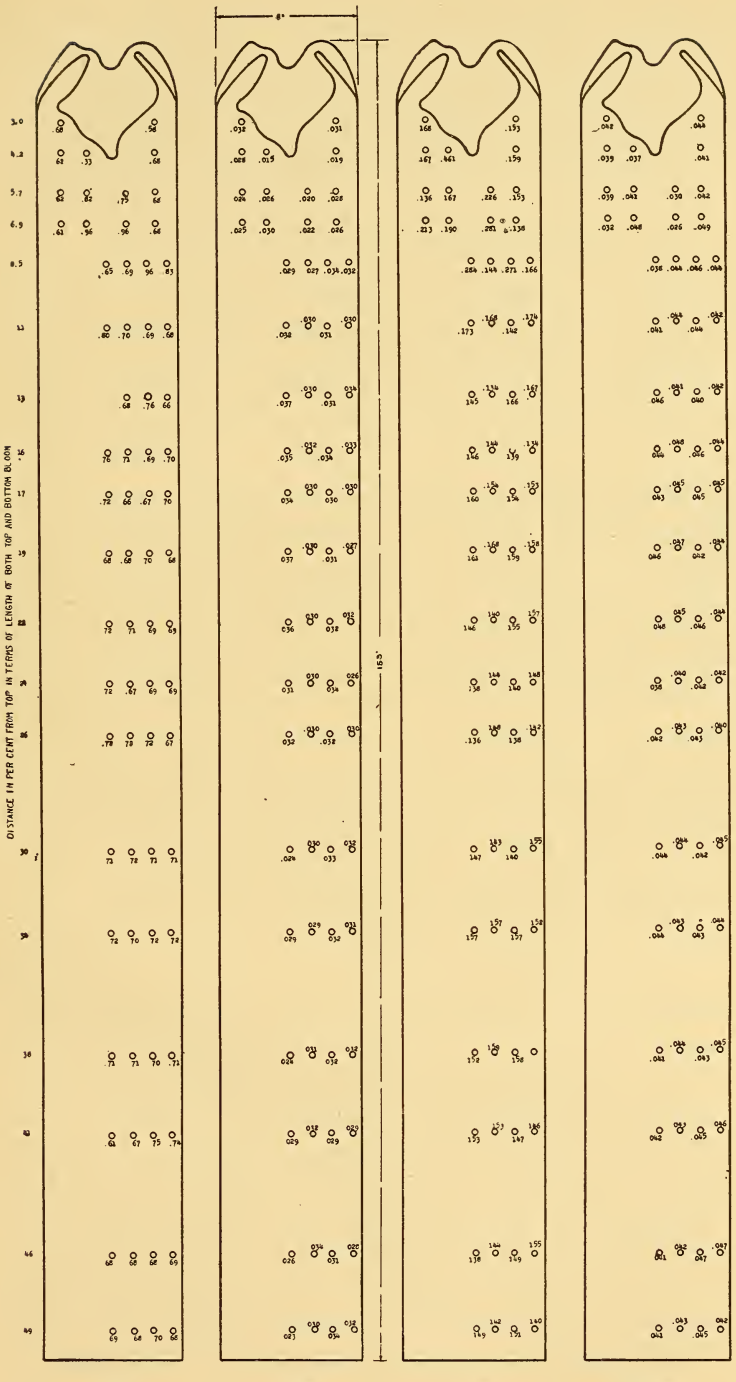


FIG. 22.—*Sections of top bloom from Hadfield ingot H5, showing chemical analysis of various positions*

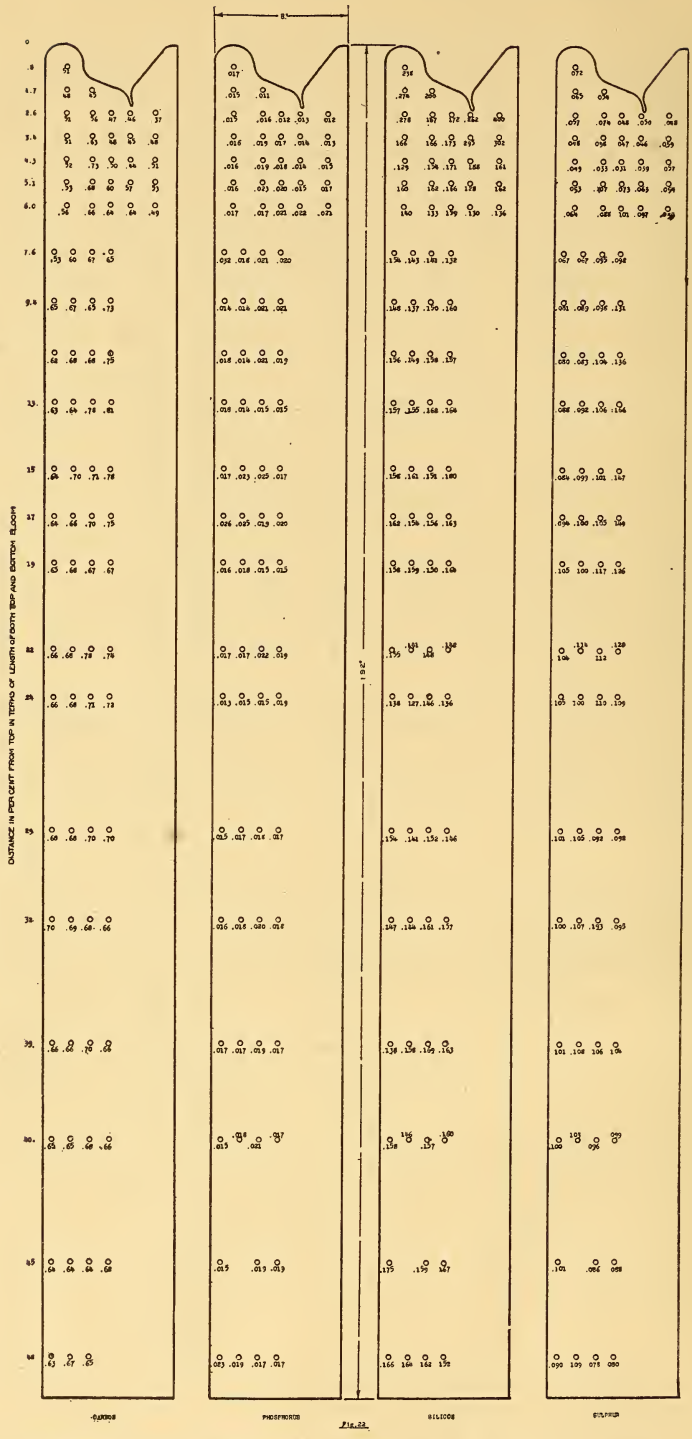


FIG. 23.—*Sections of top bloom from Maryland ingot M10, showing chemical analysis of various positions*

The Maryland rails may owe their less abrasion to their content of nickel and chromium. It would appear to be unfair to draw any general conclusions as to performance in service from so few rails as this investigation furnished, although it would not be expected that the Hadfield type of sink-head ingots would furnish any rails showing structural defects.

V. SUMMARY AND CONCLUSIONS

The object of this investigation was to determine the relation of ingot practice to the properties of rails from such ingots, and in particular the amount of total discard necessary to obtain rails free from piping and segregation above 12 per cent which had been rolled from steel made in accordance with varying melting, casting, and ingot practices.

To that end, 35 ingots made by the converter process at Hadfield's, Sheffield, England, and cast by the sink-head process with large end uppermost were shipped to Sparrows Point, Md., and rolled into rails in comparison with 15 rail ingots made in the ordinary manner with the small end uppermost. Each sink-head ingot, of 5300 pounds weight, and deoxidized with aluminum in the mold, represented a separate heat of converter steel, and all the heats and ingots were made in the same manner. The composition and properties of these ingots were of remarkable uniformity. The comparison ingots, of 7300 pounds each, were from 3 separate open-hearth heats, an intentional variation being made in the open-hearth and casting practice for each. Five ingots were selected from each of these 3 heats. Thus in reality, comparison was made of 4 different kinds of steel, of very nearly the same composition and physical properties and of two types of ingot form.

The comparison was made by rolling most of the ingots into rails and taking test specimens at each rail cut, as well as from a considerable portion of the upper part, in 5-foot steps, of the rail bar from each ingot. In this way there was obtained a detailed physical, chemical, and metallographic survey of each ingot, and it was possible to exactly delimit the regions of sound and homogeneous from those of unsound and segregated steel. Two complete sink-head ingots were cut longitudinally and examined, as well as representative blooms from both sink-head and ordinary ingots.

The results obtained indicate a decided superiority of the sink-head ingots over the comparison ingots as made of three grades of steel (Tables 17 and 18), although the sink-head ingots suffered from the disadvantage of having gone cold before rolling. The

Hadfield type of ingot required a total discard of only 18.4 per cent on the average (13 per cent top discard to eliminate piping and segregation above 12 per cent) while the average ingot of the ordinary type for rails required a total discard of 43.9 per cent (26 per cent top discard), with great variations dependent upon the furnace and ingot practices.

The comparison ingots from heat M1–M5 of nondeoxidized rising steel, chilled on top of ingot by cast-iron caps, required excessive discard to eliminate positive segregation at the top and negative segregation at the bottom of the ingot, the latter often accompanied by dangerous inclosed pipes.

The second heat (M6–M10) made of rising steel deoxidized with aluminum in the molds; the ingot tops of which were cooled with water, required the least total discard of the three heats. It was more subject to piping and less to segregation than the first heat of ingots made in the usual manner.

The third heat (M11–M15) made of quiet or "killed" steel, was not chilled on top with water or caps, and was deoxidized with aluminum in the molds. The ingots of this heat required an intermediate amount of total discard when compared to the first and second heats; this heat was the only one for which a greater top discard was required to eliminate piping than to eliminate segregation above 12 per cent. One of the ingots of this third heat contained a small pipe at the bottom, and all the rails from the middle and bottom of the ingots showed high negative segregation.

The variation of physical properties throughout the length of each ingot is characteristic not only of the type of the ingot, as sink-head or ordinary, but also of the state of the steel when cast and of the ingot practice.

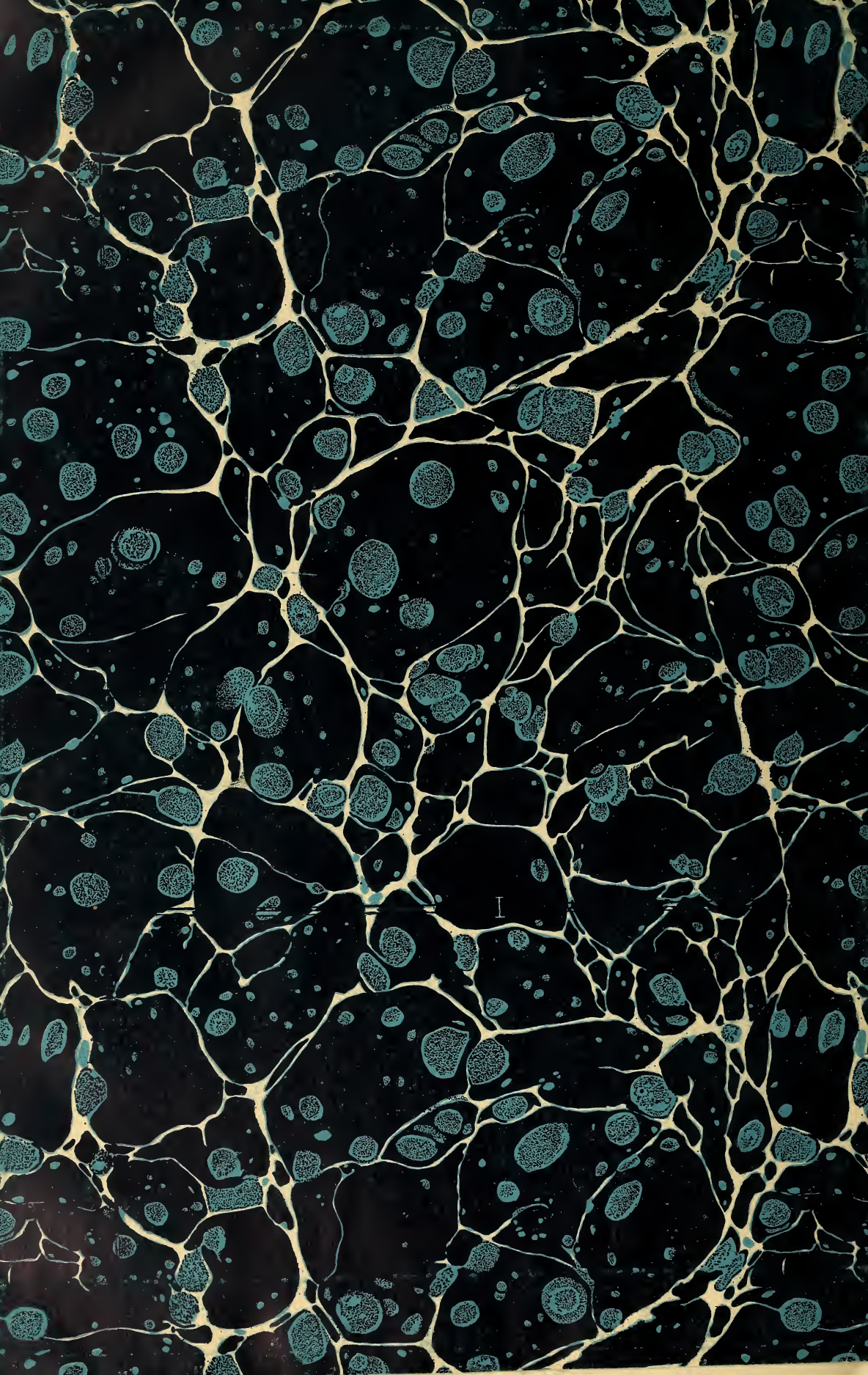
It has been established in the foregoing that, after removal of the top discard of 13 per cent, the Hadfield type of sink-head ingot is free from piping and undue segregation. The ordinary type of ingot, cast small end up without sink head, as is usual for rail ingots, requires an average top discard of 26 per cent, and the remainder of the ingot is liable to contain inclosed piping and excessive segregation. Defective rails, from the middle and bottom portion of the ingot, are not detected with certainty by means of the test for existing rail specifications, and as a result of this uncertainty rails containing pipes or excessive segregation may get into service with disastrous results.

The surface condition of the rails from the sink-head ingots was not as good as that of the ordinary ingots, but this is not considered an essential characteristic of rails from such ingots.

The markedly differing characteristics of the three heats of comparison ingots lead one to raise the question whether or not it might be advisable to specify, at least in some degree, the methods of steel manufacture or of ingot practice for rails and similar products on which the safety of the traveling public depends

While it is not claimed that the use of the sink-head process for the manufacture of ingots will solve all rail problems, it is maintained that its adoption would be a step in the right direction in view of the present heavy casualties and property losses on American railroads. The necessary changes in mill operations, it is believed, could be made without too great difficulties.

The service results, showing no failures to date, in the few rails of this investigation can not be considered conclusive one way or another.

It would be of the greatest practical importance in tracing statistically the origin of rail failures, if, in the reports to the rail committee of the American Railroad Engineering Association, they be grouped with reference to their position in the ingot, and in addition the steel manufacturing process be reported, at least briefly by such notations as rising steel capped with plates; quiet steel deoxidized with x ounces of aluminum per ton, etc. If then it be found, for a given kind of steel, there is a greater or less tendency for certain types of failure to predominate or to exist in certain definite regions in the ingot, corrections could then be made intelligently in the manufacturing process. The results of the present investigation indicates very strongly that one should expect the four types of steel and two types of ingot examined, in view of their sharply differing characteristics, to behave differently in service.

WASHINGTON, June 7, 1920.